COAL-MINING IN THE U.K.: RECENT EFFECTS OF TECHNOLOGICAL CHANGE ON PRODUCTIVITY AND SAFETY

by

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Certificate of Originality

This is to certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in acknowledgements or in footnotes, and that neither the thesis nor the original work contained therein has been submitted to this or any other institution for a higher degree.

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Signed

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Abstract

The thesis starts by defining technological change, productivity and safety. Different definitions are discussed and their merits compared.

A brief history of coal mining, together with a description of the state of the mining industry at present is given. Technological innovations recently adopted by the industry are discussed.

The concept of productivity in relation to the coal industry of the U.K., and the deficiencies of the present measurement technique, are fully explained.

Safety in the coal mining industry of the U.K. is investigated. A brief history is given, together with a full discussion of the consequences and costs of accidents.

The concept of technical productivity is introduced and its relation to total productivity explained. The total productivity concept is then applied to longwall coal faces. A multi-variable non-linear model is devised which represents mean total productivity of all longwall faces to an accuracy of about 3%. The model is tested and a forecasting method suggested.

Total productivity components are analysed and values for the productivity of various inputs during the period 1958-1980 given.

Similarly, a model for representing safety, based on costs, is introduced, tested for accuracy and its components analysed.

By applying marginal analysis to the total productivity and safety models, the influence of technological change on productivity and safety are quantified.

It is concluded that a new method for measuring productivity should be adopted, in which case total productivity would be the most realistic and comprehensive choice. The models introduced can serve as useful tools in planning and forecasting, as well as being used to measure productivity and safety. Since this work has been in progress, work at the NCB has also led to consideration of improved measures of productivity.

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Introduction

The importance of the coal mining industry for the United Kingdom cannot be over-estimated. Like any other large industry, it has been subject to booms and recessions. After a few decades of temporary recession, the role of coal as a reliable source of energy for the continued growth of the U.K. industry is now, once again, widely accepted to be vital. Forecasts anticipate the annual demand for coal in years beyond 2000 may be above 200 million tonnes, although recent economic effects cast doubt on this figure.

Having been involved in the mining industry in general for many years, and in the coal mining industry of the U.K. in particular, the writer's attention was drawn to the fact that despite numerous technological innovations, no change had been applied to the concepts of productivity and safety, and that methods used to measure both had remained unchanged for centuries. It was also noticed that in spite of claims of improved productivity, the financial state of the coal industry did not seem to have improved and the size of the government's deficit grants is increasing. The question then asked was: Does the measure of productivity used in the coal industry really measure productivity?

Since nationalization, and particularly since the late 1950's, the speed of technological change in the coal mining industry seems to have increased. A study which would measure the degree of the effectiveness of these innovations, especially as regards productivity and safety, should prove helpful in the appraisal of future investments.

Since both the fraction of coal produced from mechanized faces, and that of coal produced from longwall faces, have been increasing to the extent that in 1980 these fractions were 92.2% and 98% respectively, it was obvious that these were the dominant areas that needed emphasis. Further, to start at the most significant place in the mine, it was decided that the study would be carried out for the coal faces. The thesis is therefore about longwall mechanized coal faces.

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1. DEFINITION OF TECHNOLOGICAL CHANGE, PRODUCTIVITY AND SAFETY

1.1 TECHNOLOGICAL CHANGE

1.11 Introduction

"Innovation is uniquely a human quality and change, renewal and rejuvenation are normal, healthy human tendencies."[1]

This presentation is concerned with technological change, but since as a result of an innovation a change occurs, and these two are interconnected, some attention is also given to innovation. There is no doubt that innovation is a vast subject, meaning something new - a new idea, theory, method, machine or even a social arrangement.

Mueller[2] notices two characteristics of innovation. It is deliberate and continuous. He also claims that an organisation that does not confront change, or believes that it need not innovate, stagnates, decays and dies. This specific, clear and straightforward statement indicates the need for innovation and emphasises the significance of technological change for the continued existence of an organisation.

Innovation and change are perhaps as old as the history of mankind and they are not by any means confined to technology. One difference today is that the time gap between changes has become shorter. Napoleon said that a general would have to change his tactics every ten years if he wished to maintain his superiority. This time interval would certainly seem too long nowadays. One example of this increase in the rate of change is that, in the late 1960's, 80% of the United States college graduates entered positions which did not exist when they were born[2]. Another example is the fact that in the United States in 1970, the volume of goods

produced was 2.5 times higher than its level in 1929, but the increase in manpower had only been 20%[3]. These figures show that technology advanced by 3% per year of its level in 1929.
[(150% - 20%) ÷ (1970 - 1929) = 3.1%]

Technological changes have taken place in many different ways. In a U.S. government study[4] these have been grouped into nine categories:

1. Computerization of data processing
2. Greater instrumentation and process control
3. Trend towards increased mechanisation
4. Progress in communication
5. Advances in metalworking operations
6. Development of energy and power
7. Advances in transportation
8. New materials, products and processes
9. Managerial and related techniques

These will be dealt with later as regards the particular industry concerned here, coal mining; but it is evident that the coal mining industry of the U.K. has improved along almost all these lines.

1.12 Definitions of Technological Change

To define technological change, technology must first be defined. Mansfield[5] describes technology as "society's pool of knowledge regarding the industrial arts." It consists of knowledge used by industry regarding the principles of physical and social phenomena, and knowledge regarding the day-to-day operations of production. Technological change can then be defined as the advance of technology, often taking the form of new methods of producing existing products; new designs which enable the production of products with important new characteristics; and new techniques of organization, marketing and management.

Many different lines may be adopted to define technological change. Economists often try to do this by the use of a production function. Technological change may be defined directly or indirectly in terms of its effects on productivities of inputs.

Schumpeter[6] defines technological change as synonymous with innovation; he has also defined innovation indirectly in terms of its effect on output requirements: "We will now define innovation more rigorously by means of the production function - this function represents the way in which quantity of products varies if quantity of factors vary. If, instead of quantities of factors, we vary the form of the function, we have an innovation."

Solow[7] employed essentially the same indirect definition of technological change in his pioneering article: "I am using the phrase 'technical change' as a shorthand expression for any kind of a shift in the production function".

Schumpeter[6], Ruttan[8] and Mansfield[9] agree that many innovations (that is, technological changes) are not derived directly from predecessor inventions but occur with a frequency greatly exceeding that of well publicized, major innovations that do depend to some degree on predecessor inventions. Indeed Ruttan[8] adopts an extreme position by suggesting that it is pointless to separate analytically inventions from innovations. Instead he believes that inventions should be considered as a subset of innovations, and that the latter could be defined both directly as "the entire range of processes ... by which new things emerge in science, technology and art"; and indirectly: "technological change ... designates changes in the co-efficient of a function relating inputs to outputs resulting from the practical application of innovations in technology and in economic organization ..."

Brown[10], by fully explaining production function and abstract technology makes definition somewhat easier. He then defines technological change simply as a shift in the production function. He goes on by defining the two types of technology change, neutral and non-neutral in terms of production function. A neutral technological change is one which produces a variation in the production relation, itself, but does not affect the marginal rate of substitution of labour for capital. A non-neutral technological change, on the other hand, alters the production function and can be either labour saving or capital saving.

Hicks [11] also defines the two types of technological change in exactly the same way but Harrod[12] provides a different approach. Kennedy[13] shows that Harrod's and Hick's definitions may well refer to the same phenomenon at the economy level. Figure 1 illustrates neutral and non-neutral technological change in terms of production function. In figure 1(a), the two curves are roughly equidistant, whereas in figure 1(b) they diverge significantly.

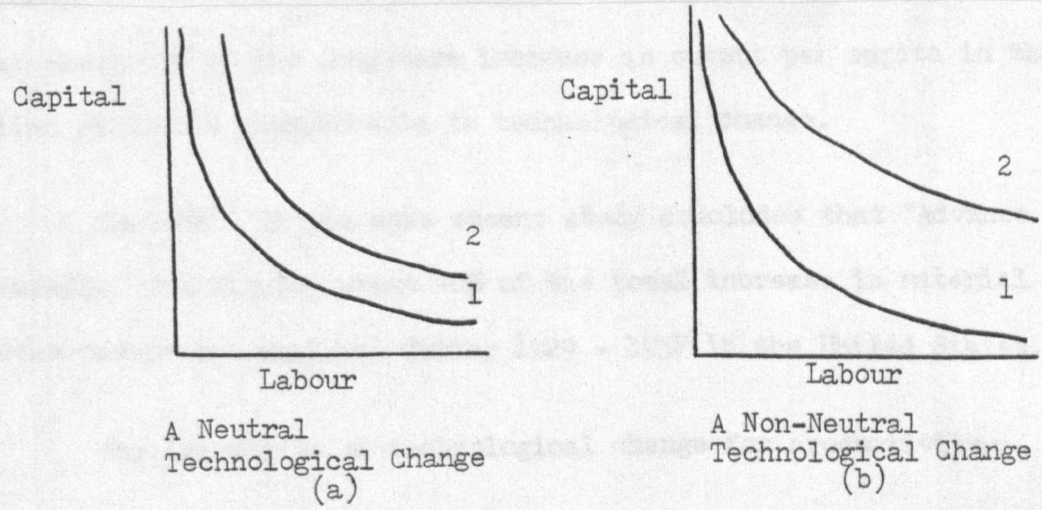


Figure 1

Two Types of Technological Change

The highest credit for definition should be given to Schmookler[14], who gives a good discussion, encompassing the ideas of all the other economists that have been mentioned above, as well as his own.

1.13 General Analysis of Technological Change

Mansfield[5] states: "Without question, technological change is one of the most important determinants of the shape and evolution of the American economy".

The upsurge in the attention given to technological change began in 1956 with the appearance of an article by Abramowitz[15]. There he found that almost the entire increase in net product per capita was associated with something other than the inputs of the physical capital stock and the services of labour, eg. improved machinery

Mansfield[5] lists and explains the various influences that technological change has had. Among these, the effect of technological change on economic growth and productivity is most important. Authors such as Fabricant[16] and Solow[7] have claimed that about 90% of the long-term increase in output per capita in the United States is attributable to technological change.

Denison[17] in his more recent study concludes that "Advance of Knowledge" contributed about 40% of the total increase in material income per person employed during 1929 - 1957 in the United States.

The importance of technological change for productivity improvements is justified by statistical evidence for the United States as fully described by Mansfield[5].

Much has been written about the new subject of technological change, but it is apparent that some aspects of it have often been either left untouched or treated superficially. For example, measurement of technological change is one of these aspects. Some analytical measurements have been done, but those who attempted to do this took an econometric line of approach with its apparent shortcomings (see section 1.14). This may well be due to the fact that different sectors of the economy at different stages of time have such different characteristics that a single formula would not hold for them all. Some criteria of technological change are, however, widely accepted now.

Some business minded economists, such as Holland[18], Larrabee et al , quoted in Silk[19] and Keezer et al[20] have explicitly stated that the attractiveness of technological change is largely due to the economic rewards that result. To justify the above mentioned statement that this fact is widely accepted, some other economists sharing similar views are mentioned here. Schmookler[21], Carter and Williams[22] Brozem[23], Sutherland[24] and Nelson[25] have similar opinions and attribute a great significance to this reward.

Minasian[26], having similar beliefs, gives a detailed justification for his opinion with the help of statistical evidence. Nelson[25], Sutherland[24] and Carter and Williams[27] also consider other motivations for technological advance to take place.

Keynes[28], Andrews and Brunner[29] and Hershay[30] are of the belief that motivations other than the economic rewards have been the main cause for change. The perceived need for survival and competition are particularly mentioned by them.

Gold[31,32] states that another criterion of technological change widely accepted is that it increases productivity and as a result yields progressively lower unit costs. It can be claimed that this is part (perhaps the major part) of the economic reward gained through technological advance, as mentioned by other authors, and that it has only been specified here.

A number of experts in the field of technological change including Schumpeter[33], Maclaurin[34], Galbraith[35] and Machlup[36] claim that it is a criterion of technological change that major technological innovations occur primarily by increasingly complex and heavily financed research and development programs - with yields roughly proportioned to the resources applied. These believe that major innovations incorporate so much effort and take such a long time that the random element inherent to research work is eliminated. If this idea were absolutely true then measurement of the rate of technological change would be easier than it is. A U.S. Government study[4] concludes that the rate of technological change is closely related to the rate of investment, the level of economic activities and the level of demand.

Opposing the views expressed in the previous paragraph are Jewkes et al[37], Kuznets[38], Wiesner[40] and particularly Heald[39]. Amongst these, Nelson[25] gives an excellent general view of the relationship between the amount of effort spent and benefits gained.

Mansfield[41] and Comanor[42] have also tried to find a relationship between expectation from the research and the effort spent, using empirical data.

A further criterion can be deduced from the fact that technological change yields increased productivity, being that it increases profitability and results in economic growth. Mansfield[41, 43] and Comanor[42] agree with this and Gold[31,32] asserts that this criterion is now widely accepted. Many other economists, however, notably Griliches[44] and Sanders[45] oppose this view, believing, in brief, that there is no guarantee that technological change alone, without other contributory factors and appropriate economic circumstances, would result in economic growth.

If all the above criteria of technological change somehow hold true, then a further one will complete the cycle, that is, increased profitability and growth would create incentives for further research. Although these criteria complete the cycle so neatly, it is apparent from the literature that there is no strong support for the general applicability of any one of them.

Reviewing the relevant literature, it seems that certain effects are expected by management and engineers to be gained from technological innovations. Following are the most important ones:

1. Improved materials, reduced waste and the development of byproducts should tend to lower material inputs per unit of output, thereby reducing unit material cost and their proportion of total unit costs - illustrated best by Fabricant[46].

2. Task specialisation, method improvements and mechanization should tend to reduce unit labour requirement and hence both unit wage costs and the ratio of wages to total cost - claimed and proved on a theoretical basis by Jerome[47].

These together with some other minor expectations were examined by their great admirer Gold[31], applying them to six industries over periods of 30 - 40 years. He concluded that, the results did not support the expectations associated with technological innovations and in two cases, the total materials cost even showed an increase.

Since one of the main concerns here is productivity and its relation to technological change, this matter should be examined further. One type of productivity, namely labour productivity, although by no means equivalent to total or real productivity, but still of much importance because it can be related to a nation's standard of living, has been used extensively. A rapid rate of technological change is likely, other things being equal, to increase labour productivity. Although labour productivity is a determinant of the rate of technological change, it can not, in isolation, be used to measure the rate of technological change with any degree of accuracy since there are other factors influencing it. This method has however frequently been used. Other factors influencing labour productivity include the extent to which capital is substituted for labour in response to changes in relative input prices, and the extent to which productive capacity is used. Also the rate of growth in labour productivity is dependent upon the nature of technological change. Some innovations, such as transport machinery in coal mines, are labour saving; some, although few in number, are capital saving, and some are neutral and have been adopted for other reasons, such as power supports which are adopted mainly for safety purposes.

1.14 Measurement of Technological Change

It was mentioned in Section 1.13 that the rate of growth of labour productivity has often been, despite its inadequacies, used to measure the rate of technological change. Taken one step further, i.e. to total productivity, it becomes a slightly more reliable measurement. Mansfield[5] has stated this idea, but like other economists has considered total input as being that of labour and capital only. Domar[48] introduces the formula for level of technology:

$$\frac{q}{zl + vk}$$

Where: q is output (as a percentage of output in some base period)
l is labour input (as a percentage of labour input in some base rate
k is capital input (as a percentage of capital input in some base period)
z is labour's share of the value of output in the base period
v is capital's share of the value of output in the base period
provided v and z are unchanged

Substituting for q, l and k over a given period, the value of productivity can be computed for that period.

Although this is more comprehensive than using labour input only, it has the disadvantage of assuming that the marginal output is altered only by technological change and that the output/input ratio remains constant and independent of the ratios of the quantities of the inputs.

From all economists who have used productivity ratios to measure technological change, the work of Abramowitz[15], Solow[7] and Salter[49] is of particular significance. They take different views and arrive at interesting conclusions.

Butcher[50] used productivity measures to detect technological change in agriculture. He measured the arithmetic total factor productivity associated with the work of Kendrick[51], and used labour in terms of man-hour. Other inputs, as well as labour and output were considered in terms of deflated values. While he arrived at a numerical value for the rate of technological change, he also drew a very interesting conclusion, viz that labour productivity growth, on its own, overstates the effect of technological change. The equation used by Butcher[50] is:

$$\frac{Q_2}{Q_1} = A \left[W_0 \left(\frac{L_2}{L_1}\right) + i_0 \left(\frac{K_2}{K_1}\right) \right]$$

Where: Q_i is output in ith year
A is efficiency variable
L_i is labour input in ith year
K_i is capital input in ith year
W_0, i_0 are input prices in base year

As mentioned in Section 1.12 economists have tried to analyse technological change by the use of a production function. Therefore if the production function were readily observable, a comparison of that at two points in time would provide the analyst with a simple measure of the effect of technological change during the intervening period. If there were constant returns to scale, the characteristics of the production function at a given date could be captured fully by a single curve that would show the various combinations of labour and capital inputs per unit of output that are technically efficient.

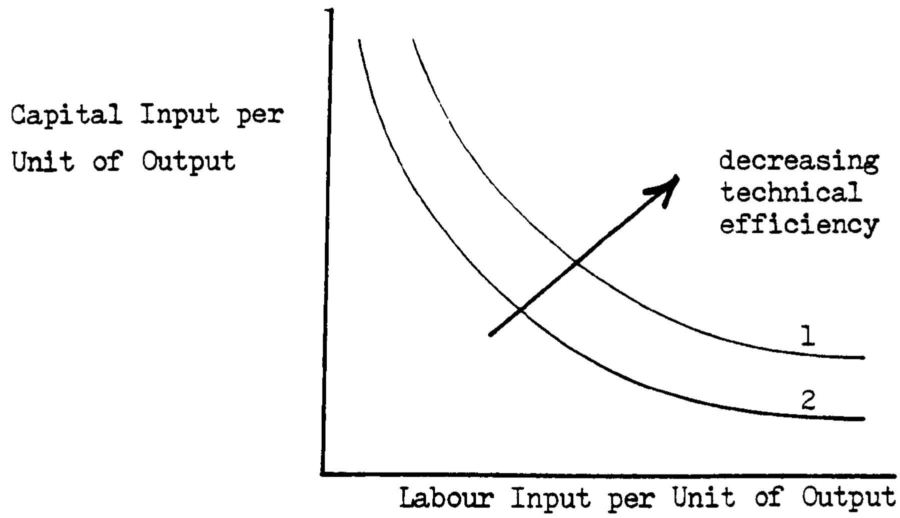


Figure 2 Use of Production Function to Analyse Technological Change

A shift in the curve from position 1 to 2 represents a technological change.

Economists have also tried to devise better measures of the rate of movement of the production function. These measures rest on somewhat different assumptions about the shape of the production function. For example, Solow[7] provided an estimate of the rate of technological change for the non-farm economy of the United States during 1909 and 1949. His assumptions were:

i) Constant returns to scale
ii) Capital and labour were paid their marginal products
iii) Technological change was neutral

Massel[52] also carried out a similar analysis for the United States manufacturing industry. His conclusion was that technological change had taken place with a rate of 3% per annum (as compared with Solow's result - 1.5%).

One of the first economists to measure technological progress by estimating a production function directly was Tinbergen[53]. He used the Gobb-Douglas production function of the form:

$$X = A L^{\alpha} C^{\beta}$$

Where X is production A is a scale parameter, and α and β are elasticities of production with respect to labour (L) and capital (C) respectively.

His method had its limitations and more recently there have been more elaborate attempts to estimate technological change in Tinbergen's fashion.

Mansfield[54], in tackling the measurement problem states that his results based on data regarding ten large chemical and petroleum firms and ten manufacturing industries, are that the rate of technological change is directly related to the rate of growth of accumulated research and development expenditures made by the firm or industry. He has also confessed that correlation does not prove causation.

Denison[55] measured technological change by quantifying all its components, such as productivity benefits, design and product innovations attributable to research, economies of scale, improvements in the organization of markets such as removal restrictions on the mobility and economic effectiveness of resources and the managerial efficiency. The total of these represent technological progress, but the main problem would be quantification and its reliability. Even this method, and in particular Denison's work has been logically criticized by Abramowitz[56].

Another very common measure of the effects of technological change is to estimate the reduction in total unit cost. Both Mansfield[9] and Salter[49] have asserted that this measure is of primary interest, both ex ante and ex post, to the potential or actual adopter of process innovations.

There are many ways of measuring technological change and they are all claimed to be different, but when examined in depth the principles of many of them seem to be the same, and only the directions of view, in order to suit individual cases, are different.

1.15 Problems in Measuring Technological Change

Most measurement methods tackle the problem by indirect means. This is to measure technological change by measuring its consequences. There is obviously an inherent deficiency in such methods. Also, much emphasis has been put on the changes in output and since technological change is not the only factor influencing output, its isolation is a difficult task.

On the other hand technological change has a number of effects, and only some of them can be easily quantified. Although economists have attempted to quantify social and other non-physical influences, their methods become so complicated that little accuracy or realism can be expected from them.

There are difficulties, also, in measuring inputs, the measurement of aggregate capital being a particularly nettlesome problem. In addition it is difficult to adjust for quality changes in inputs. Robinson[57] gives a good account of these difficulties and the degree of accuracy of measurement.

Strigler[58] describes another problem associated with technological change measurement, namely that the measures often assume that there are no economies of scale and technological change is neutral. There are some obvious deficiencies associated with these assumptions.

Further, when one compares a number of studies, there are considerable differences in the estimated rate of technological change in particular industries. Apparently the results are quite sensitive to the detailed assumptions that are made and the data that are used.

1.2 PRODUCTIVITY IN GENERAL

1.21 Introduction

Productivity has been an everyday word for the past few decades, perhaps as a consequence of the full employment situation in the post war years, to the extent that politicians and economists feel that the nation's general economic health is dependent upon productivity.

In spite of much talk of the concept, productivity remains as one of the most elusive terms in the literature and it has only been SPOKEN about in woolly terms. Indeed there has been more talk about the subject than understanding. Productivity improvements have been the declared aim of governments but there can be little certainty in achieving this goal without a firm understanding of the concept. Misunderstanding has led to abusing the word and there can be only a few words more abused and more misapplied than productivity.

There is, however, no question that productivity improvements are highly desirable and it is an area where government, management and labour have strong mutuality of interest.

Gold[59] states that productivity analysis enables management to:

a) Appraise alternative means for changing productivity
b) Appraise managerial alternatives in the application of such innovations, and
c) Determine the effect of past as well as prospective innovations

1.22 Definitions of Productivity

Following quotations are from people met casually[60].

... I think it is to do with producing more HARD things ... (accountant's clerk)

It is the ratio of output to inputs of MEN and MATERIALS (teacher)

It is to do with LABOUR and MATERIALS "COST" (man installing building boiler)

It is the ratio of OUTPUTS to INPUTS (chargehand of first man).

The dictionary provides a starting point. Productivity can be defined in a general sense as "the quality or state of being productive"[61]; it is the possession or use of power to "cause or bring about, make or manufacture"[62].

Given this type of definition, it is possible to include the productivity of such varied subjects as a violinist, an apple tree, an office or a coal mine. These definitions are useful, since they imply that the use of productive power can be measured by the RESULT of that use.

Productivity is generally interpreted as efficiency in industrial production[63], to be measured by some relationship of output to input. It is also defined[64] as the ratio of what is produced to what is required to produce it.

The Concise Oxford Dictionary (6th edition) says:

Productivity - capacity to produce, quality or state of being productive; production per unit of effort; effectiveness of productive effort, especially in industry.

These are taken one by one.

1. 'capacity to produce' seems to imply having different kinds of resources available; but surely productivity is more than simply having resources available.

2. 'Quality or state of being productive', although a woolly definition, seems to be getting closer to the true meaning of the concept.

3. 'Production per unit of effort' is getting much nearer the mark, although it is an absolute figure, however expressed; an absolute figure may not always be helpful unless it can be compared with another absolute figure; and what about non-human facilities?

4. 'Effectiveness of productive effort' is a good definition, although it does not differentiate between productivity and efficiency.

A booklet published by ICMA[65] defines productivity as "the effectiveness of the expenditure of resources required for production of goods and services".

The BIM thinks of productivity like this[66]: Productivity denotes the effectiveness of labour and capital in the creation of wealth.

The ideas considered here seem to be that productivity can be attributed to the use of resources. Labour, materials and capital have been mentioned. It is interesting to note from the OECD[67] definition that 'when used without qualifications, the productivity of labour is understood'. This idea was echoed in the Economic Progress Report[68], which suggested that increased productivity, briefly and in summary, was a reduction in labour cost of producing any amount of goods.

It is not easy to define productivity so that it would be meaningful, comprehensive and useful in different cases and generalization is often associated with many problems. For this reason, any study of the concept, in a particular industry or firm at a particular time, must first define it according to the special requirements of the study and characteristics of the case under consideration.

Gold[69] states that widely used concepts of productivity have three serious shortcomings:

1. Output per man-hour does not measure productive efficiency AS A WHOLE, or even the productive contribution of LABOUR.
2. Increase in output per man-hour may or MAY NOT be desirable and may or MAY NOT reduce unit LABOUR COST.
3. Even if increases in output per man-hour are accompanied by only proportionate increases in hourly wage rates, production costs are more likely to INCREASE than to remain unchanged in capital dominated industries.

Another problem associated with defining productivity lies in the fact that different groups involved emphasize different definitions. It is usually the case that an engineer is interested in labour productivity with no regard to even the unit cost of labour; the economist takes a more comprehensive view by considering capital CHARGES as well as labour; the accountant relates productivity directly to profitability; management have different views to the concept depending on the state of the industry or firm; the labour force is now merely interested in labour productivity; governments concerned with profitability also show interest in total production volume and the nation as a whole takes an entirely comprehensive view to productivity, involving all financial and physical factors as well as intangible products and by-products. The analyst must therefore, also, take a particular view of the concept, define it and draw guidelines within which he can manoeuvre.

Eilon and Soesan[70] notice this fact by stating that guidelines as how to define and measure productivity may be obtained from an analysis of why we should wish to measure it ... which could be for strategic, tactical, planning and other management purposes.

In this study productivity will be defined and guidelines specified in a later chapter, so that the most relevant, realistic and comprehensive approach in the particular area concerned here, will be adopted.

1.23 Measurement of Productivity

Productivity is easier to discuss than it is to measure. Talk about productivity and its improvements goes on in many quarters, including the shop steward's office, the directors' board room and the

House of Commons. The degree of concern with the subject which exists in the established industrial nations and the developing countries, might result in the layman being surprised at a situation in which the level of concern considerably exceeds the level of effectiveness of the techniques so far developed for analysing and measuring productivity. Indeed productivity is a variable which to date has not been analysed and measured with complete effectiveness.

It should be clear by now that an analysis of productivity must be embedded in the cost and profitability structures. Also, as stated earlier, to determine how productivity is to be measured in a particular case, the question "why to measure it" should be asked. Many lines of approach have been taken to measure productivity, but although beginnings are similar, means and results are often different. Following is a summary of the relevant literature.

1.231 Use of financial ratios

Most widely used by accountants and economists, but seldom as a basis for productivity negotiations.

1.2311 Input-Output Approach

A totally financial measure of profitability rather than productivity has been used to measure the latter. Being similar to the total productivity concept except for the non-existence of physical factors, it simply measures the total money value of all inputs and outputs and the ratio of output to input is then taken as measure of productivity. It is more suitable for firms with many different outputs and it solves the problem rooted in the heterogeneity of physical outputs.

1.2312 Return on Investment Approach

A more complicated approach used for example by Risk[71], who suggests that by dividing assets between departments, the respective ratios of outputs to assets can be used to measure the productivity of different departments. This again, being quite a simple method, is hardly a comprehensive one.

1.2313 Profit on Investment Approach

This is used as an alternative measure to the return on investment.

The work of the centre for interfirm comparison in Britain applying this method uses the ratios in figure 3.

The three ratios mentioned above, by purporting to measure productivity, illustrate different possible answers to the question "why measure it": input-output approach, to measure the overall monetary performance of an organization; return on investment, to measure performance of divisions of an organization or individual projects; and profit on investment, to measure profitability of different departments of an organization.

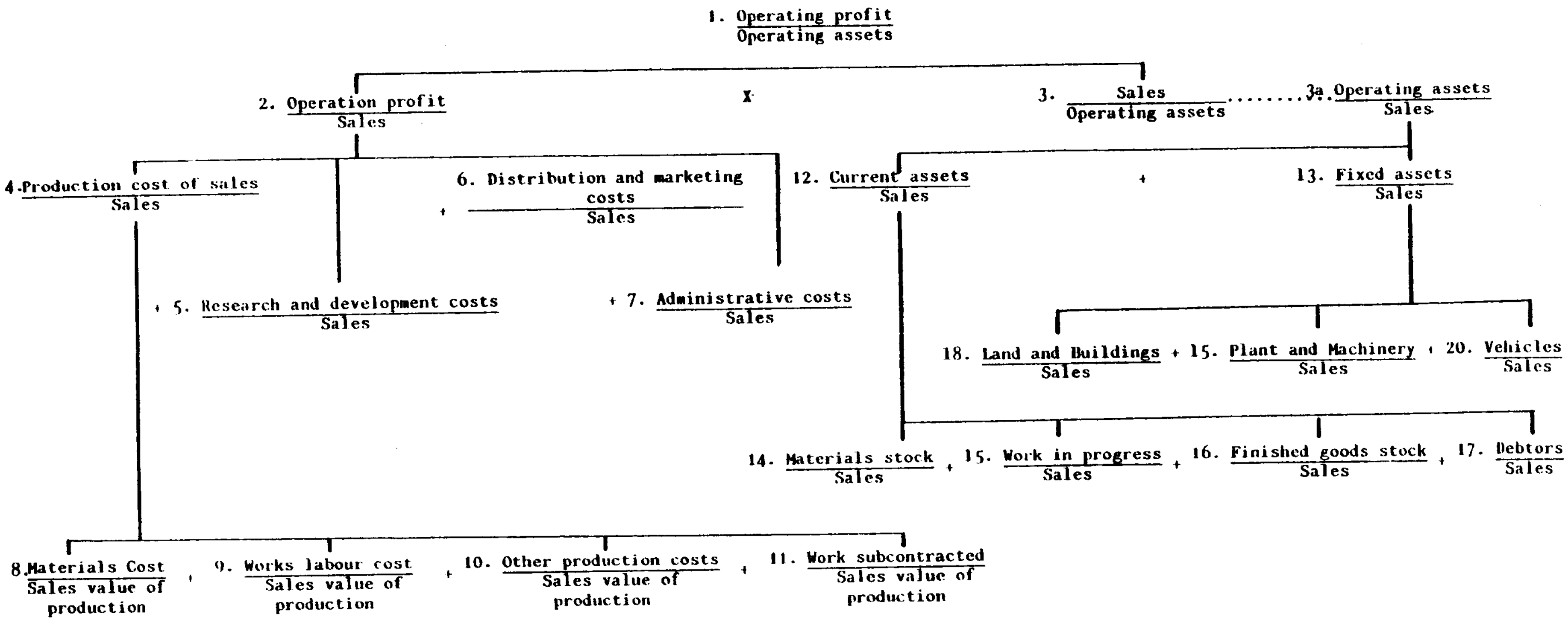


Figure 3: Structure of financial ratios
(from reference number 72)

1.232 Value Added

This is simply the difference between the value of products and their cost, is again a purely financial measure and incorporates all the weaknesses of accounting systems. Its main followers such as Ball [73], Morley [74] and Robertson[75] have discussed the usefulness of the tool in depth, but it is asserted even by them that it cannot be a useful measure of PRODUCTIVITY. It is, however, arguably superior to the rate of return on investment, since it is more responsive to the product price.

1.233 Use of Production Function

This is a purely theoretical method and more useful for efficiency rather than for productivity, was used by Farrell[76] and Sahgal[77] who tried the method using eleven two input-single output cases and his results were not satisfactory. In this method, technical efficiency is used as a measure of productivity.

In figure 4, EE' is the locus of all points representing the most efficient ways of production in the present state of technology. Ratio $\frac{OB}{OA}$ is then taken as a measure of productivity, where A, for example, represents the actual inputs required.

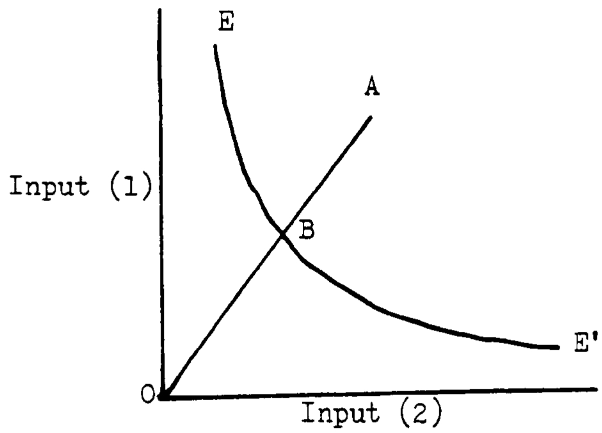


Figure 4

Use of Production Function to Measure Technological Change

Its disadvantages are its inability to be used in the case of multi input-multi output; difficulties encountered in constructing EE'; and the fact that it does not measure productivity, are too serious to grant the method credibility for practical work.

1.234 Operational Research Methods

These methods can be used to measure productivity in small enough production systems, where data can be obtained with a high degree of accuracy. Different methods of this kind all have the characteristic of revealing reasons for low productivity. Ijiri[78], for example, starts with a number of desirable goals, financial and physical, and measures the extent to which these are missed. Eilon[79] also used operational research methods, but his method had strict limitations since it would not suit complex production processes.

These methods are useful tools but not suitable for productivity measurement in large sectors of the economy.

1.235 Costing Approach

Another approach to measure productivity that was mainly applied by Bahiri & Martin[80, 81, 82]. It takes the contribution of different products as indicative of productivity. Being similar to the ratio analysis, it incorporates the shortcoming that again it does not differentiate between efficiency and productivity, and indeed it is not a comprehensive measure.

Tolkowsky[83] gives a full description of the method, its applications and merits.

Transfer prices have also been used to measure productivity, by Horngren[84] for example. This method can only be used in relatively simple production processes in which fixed costs and distribution costs are not high.

1.236 Empirical Methods

This approach is often superior to all aforementioned methods, as it can be defined, formulated, tested and analysed according to the needs of a particular case. It is impossible to devise a specific non-empirical method which would measure productivity in all cases, in depth, comprehensively, from all points of view, or for different purposes. Empirical methods can have the advantage, in some circumstances, of practicability.

Bowey & Lupton[85] adopt several parameters such as the employees' replacement period to measure labour productivity. Rice[86] takes an entirely physical approach and argues that the ratio of actual output to potential output is a good measure. British Ship Research Association[87] and the shipbuilding industry of Japan[88] have taken some elaborate empirical approaches to measure labour productivity.

1.24 Labour Productivity

This is by far the most commonly used measure of productivity, mainly due to the simplicity inherent to the input measurement. Another reason for its being so prominent is because of its effect on wage negotiations.

The method is clearly open to the criticism that it relates the changes due to all factors contributing to productivity, to only one factor, labour. This has been the subject of much discussion and economists have written a great number of books and articles about the matter. Smith[89], for example, seeks to prove that this measure does not represent a practical method for assessing total productivity. He also points out that in productivity bargaining, in which improved utilization of labour is the key part of the argument, interest should centre on the fact that labour is an inseparable part of the total input to production, and can not easily be isolated for analysis.

Gold[59] states that even casual examination of modern industries demonstrates that labour productivity measures neither the efficiency of production operations as a whole nor the efficiency of labour's own efforts. Production usually involves integrating the contributions of many kinds of materials and purchased supplies, a variety of labour skills, numerous types of capital facilities and equipment and a wide array of technical and managerial efforts in order to fabricate a range of products. Appraisal of the efficiency of this entire complex of activities must, to be realistic, encompass all of the inputs and outputs. But labour productivity measures ignore all inputs but one, thereby encouraging gross errors both in evaluating the effects of changes in this measure and, as of particular interest in this study, in using it to appraise the desirability of prospective innovations.

Furst[90] states: "... output results from a contribution of ALL the factors of production ..... it would be equally interesting to relate it (output) to any of the other factors."

A word in favour of labour productivity would be that of Easterfield [91]. He argues that from the national standpoint and in the long run, labour is the only scarce resource, and raw materials and capital are produced, ultimately, by labour. Against this will be the argument that even in the long run at the present time labour does not seem to be the only scarce resource. Indeed today land, fuel and minerals are of similar scarcity. Also the two qualifications, over a wide enough economy and on a long enough time scale, are not easily met, and productivity analysts are not often interested in it. It seems probable that the particular concentration of the United States on labour productivity derives from historical circumstances - an economy with plentiful raw materials and a shortage of labour.

It can also be asserted that productivity can be defined as labour productivity in some special cases and depending on what one is considering. The case of a coal mine in the nineteenth century would be one example where on the one hand labour costs represented a large part of total input costs and on the other hand there was a general shortage of manpower in the industry.

At an industry level, labour productivity is rather difficult to define and measure, due to the fact that its relationship with output is obscured by other factors. In particular, increased labour productivity may not reflect the utilization of all labour in that industry and may be reflected in the productivity of other user industries.

Smith[89] asserts that basically there are two types of definitions for productivity in existence - the ideal type, concerned with total productivity, and the partial and practical definition limited to labour productivity. He further argues that although the word 'ideal' has been used to describe total productivity, the truth of the situation must be that the only meaningful definition of productivity is one which admits the full complexity of the production system and which is concerned with the relationship between all outputs and, particularly, all inputs. With labour productivity all other inputs are automatically ignored; their influence on output and indeed on labour remains unknown. At the same time these influences make labour productivity a somewhat meaningless difinition, in that it is not known how far output is a result of other factors.

Emphasis on labour productivity can therefore only mislead the analyst into inaccurate assessment of the utilization of labour and provides him with no assessment of the utilization of capital, methods and organization.

It is therefore concluded here that:

a) It is impossible to measure labour productivity due to inseparability of one input from others, and

b) Even if it were possible, it would not REALLY measure productivity.

1.25 Total Productivity

Indeed the most meaningful, useful and comprehensive method to measure productivity. It is simply the ratio of total outputs to total inputs and elaborations are made in accordance with particular cases. It is therefore obvious that a single formula can not be devised which would be applicable in different cases.

The main disadvantage of the method lies in the difficulties encountered in evaluation of the two aggregate components.

Application of the concept to the case of longwall coalmining is dealt with in detail in Chapters 4 and 6.

1.26 Problems in Measuring Productivity

The productivity of a nation is almost out of question to be measured accurately, because so many interrelated variable factors influence the end result. It is quite easy to say productivity is the ratio of output to input. But in the case of a nation what is output? Whatever it is, its components could not be measured in common units, and the result is never guaranteed to be a reliable one.

In the case of an industry such as coal mining where output can be asserted to be easier to measure, due to the relative uniformity of the product, difficulties arise when measuring input. In order to produce something many things are needed for instance: people, capital, land, facilities, machine tools, mineral deposits, energy resources, ingenuity, creativity, climate, electric power, organization, enthusiasm and national pride. How difficult these are to be measured is obvious. The problem is eased to a good extent when only changes of productivity are of interest, which is the case most of the time . In this case most of the variables become constant over the time, leaving those which are easier to measure.

Eilon and Soesan[70] have listed four problems associated with productivity measurement. These are:

1. Measuring output, especially in the face of changes with time in the design, sizes and types of individual products as well as in the proportions of different product lines.

2. Measuring inputs, and accounting for the great multiplicity of types of materials, facilities and equipment usually encountered, as well as the multiplicity of labour and salaried skills to be encompassed in the face of changes in the composition of each of these major input categories over a period of time.

3. Determining which particular input-output comparisons are most relevant in evaluating the performance of various operations and units of concern to management.

4. Interpreting such findings with due regard to the need to differentiate between the influence of internally

controllable and externally imposed factors.

Gold[59] states that some of the major problems of measuring productivity are rooted in:

a) The nature of the phenomena to be encompassed,
b) The requirements of rigorous statistical treatment, and
c) The need to interpret resulting data within the context of the evaluative frameworks of management, investors, trade unions and government bodies.

He too believes that difficulties in the first group arise from: "the multidimensionality of most inputs, outputs and other elements of economic activities, the tendency for the characteristics of such economic elements to change through time, the difficulty of measuring some of these characteristics which seem important, and the inevitable heterogeneity of the limited number of categories into which the widely differentiated units must be gathered to facilitate analysis. Such difficulties are intensified by the requirement of statistical methodology for homogeneity within categories, comparability of data through time, validity of samples and estimates of the precision of measurements."

Economists such as Gold[59, 92], Fabricant[93] and Schmookler[94] have listed and explained numerous problems associated with productivity measurement and they have indicated, described and prescribed remedies for some minor and rare problems that are of little practical value. The summary of their statements is that the main problem one would encounter in measuring productivity is measurement of total inputs and outputs! The rest are only elaborations of these.

1.3 SAFETY IN INDUSTRY IN GENERAL

1.31 Introduction

There is at least one thing that all of us engaged in industry agree about, Lord Beeching[95] wrote: we all wish to prevent accidents.

To function at full capacity man must preserve his health. From an ethical standpoint man owes it to himself and those who depend upon him to preserve himself in order to function at his best, and owes it to all persons to be considerate of their lives, limbs and possessions[96].

There are believed to be 900,000 accidents and cases of industrial diseases at work every year in the U.K., costing £600 million and involving 24 million man-days lost. There are 400,000 killed or injured on the roads, 2,000,000 accidents in the home and 150,000 miscellaneous accidents. There are therefore, more than 3,000,000 accidents every year in this country which need medical treatment[97].

1.32 A Psychological Approach to Safety

Statistical evidence over the past several years points to the fact that approximately 20% of the people have most of the accidents while the remaining 80% remain relatively free from accidents[98]. Another statistic generally accepted today is that approximately 80% of accidents are caused by human error. As will be seen later, this is of particular significance in coal mining, to the extent that the higher the number of children a miner has the more liable he is to be involved in an accident.

The importance of psychology in the occurrence of accidents is also proved by a study made by Hersey [99]. In this study he examined 440 industrial accidents. Approximately half of them occurred when the workers were in a low emotional state. He also found that about 20% of the observed accidents happened when the workers were in an elated state. He further estimated that workers are in a low emotional state not more than 20% of the time. This indicates that a worker is four times as likely to have accidents in a low emotional state as in normal state.

1.33 Definitions of Safety

The dictionary[63] meaning of 'safety' is: "being sure or likely to bring no danger". It is obvious that this definition is far from being comprehensive. First the word 'danger' is defined in dictionary as "liability or exposure to harm". The combined expression would still seem somewhat obscure, since virtually each one of the words will have to be defined further.

Another appraoch would be to define 'accident' and postulate that it is opposite to safety. The same source provides: "events without apparent cause, unexpected, unintentional and chance misfortune". This definition has many apparent shortcomings.

Crane[100] wrote an article on various meanings of the word 'accident' which illustrates the confusion that often arises from its different uses.

Authors have attempted to define accidents, many of whom associate them exclusively with injury or damage. This being a fairly recent tendency, it would seem to one that it is perhaps a spin-off from the Factories Act[101]. The Act itself only defines notifiable accidents - not satisfactory for our purposes. One difficulty with equating accident with injury or damage is, however, that it leaves one to find another word for other unintentional events.

Heinrich[102] and Bird[103] on their studies of accident prevention define 'accident' as: "an unplanned event which has a probability of causing injury or property damage". This definition although is wider than the previous ones, but still excludes many unintentional events.

In the review of literature regarding accidents, one encounters widely different definitions. While for example, most dictionaries define it as an unintentional event, Kafka[104] states that "accidents exist only in our heads"; His Royal Highness Prince Charles[105] said once: "there is enormous satisfaction in achieving something which is potentially hazardous ..."; and Nietzsche[104] claims "a heart full of cheerfulness and courage needs a little danger from time to time, or the world gets unbearable".

It is not really easy to define 'safety', or 'accident' as its opposite, and in particular to outline what it involves. Safety however, does involve the conservation of human resources and materials.

A quotation from King and Magid[106] with some modifications and additions will clarify the matter - the example of a banana skin on the pavement.

Pedestrian (1)	sees the banana skin and does not step on it.
Pedestrian (2)	seeing the banana skin, reduces his speed and steps over it carefully, so as not to collide with other walkers.
Pedestrian (3)	steps on the banana skin, slips, but recovers his balance and proceeds without collision, damage or injury.
Pedestrian (4)	who was carrying a bottle of wine, steps on the banana skin, slips, drops the bottle which breaks, but recovers his balance and walks on uninjured.
Pedestrian (5)	steps on the banana skin, slips and falls, cutting his hand slightly.
Pedestrian (6)	steps on the banana skin, slips and falls, breaking a wrist and tearing his trousers.

It is now possible to compare various definitions with reference to the example easily. The Act's definition, for example, would only call the action of Pedestrian (6) an accident. Some people would say that Pedestrian (3) had a "near miss" accident, but this is strictly incorrect. According to a wide definition, Pedestrians (3), (4), (5) and (6) were all involved in accident. This would be compatible with the definition given by Heinrich[102] and Bird[103].

Safety then can be defined as: "the minimization of injury and loss resulting from non-deliberate acts such as accidents and calamities"[107].

1.34 An Historical Review

Efforts to protect man against injury from the tools he uses are very old. Arm-protecting plates, that is, plates protecting the inside of the left wrist against the recoil of the bow string, seem to have been used in Central Europe in the earlier stone age (Paleolithic age).

Industrial safety as a subject on its own is relatively new. Petersen [108] draws a line at the year 1911, and claims that progress in industrial safety before then was practically non-existent. Although in some countries such as the U.K. there were already some regulations, it was really after 1911 that the law tended to protect workers against industrial accidents. It can be claimed that as a result of various acts enforced, which entitled workers to receive payment following accidents, management found it financially sounder to prevent accidents than pay for their occurrence.

In the early years efforts were almost entirely spent on improving the working conditions and it was in 1931 that the revolutionary book of Heinrich[102] suggested that people cause more accident than unsafe conditions do. He provided a framework for safety practice, brought all ideas together and defined some excellent principles out of the previously uncertain practices. The marked progress in safety after 1931 is asserted by some authors to have been the result of his book.

From the early 1960's to mid 1970's the picture is somewhat different and in many countries safety standards seem either to have remained stagnant or reduced. Figures for the United States, for example, are given in Table 1.

		1961	1975
Frequency Rate	(number of accidents per million worker hours)	5.99	13.10
Severity Rate	(number of days lost per million worker hours)	666	752

Table 1 - Safety Statistics in the United States (from reference number 65)

As regards health, in 1912 there was held in Brussels a meeting of the International Congress on Occupational Accidents and Diseases. A question was asked about measures in force in the United States to control industrial lead poisoning. The answer given was: "... but it is well known that there is no industrial hygiene in the United States".[109]

It can not be denied that safety standards have improved markedly in the twentieth century, nor can one ignore the fact that U.K. compares favourably with other countries with regard to the prevention of industrial ill-health and accidents, but as Sir Bernard Braine M.P.[106] stated in 1979, the toll of avoidable death and injury is still far too high for complacency and in some occupations it remains stubbornly and disgracefully high.

Teleky[109] gives a full description of the history of industrial health and safety in Western Europe and the United States, examining the effects of various actions which have admittedly tended to improve safety, particularly those of research and legislation.

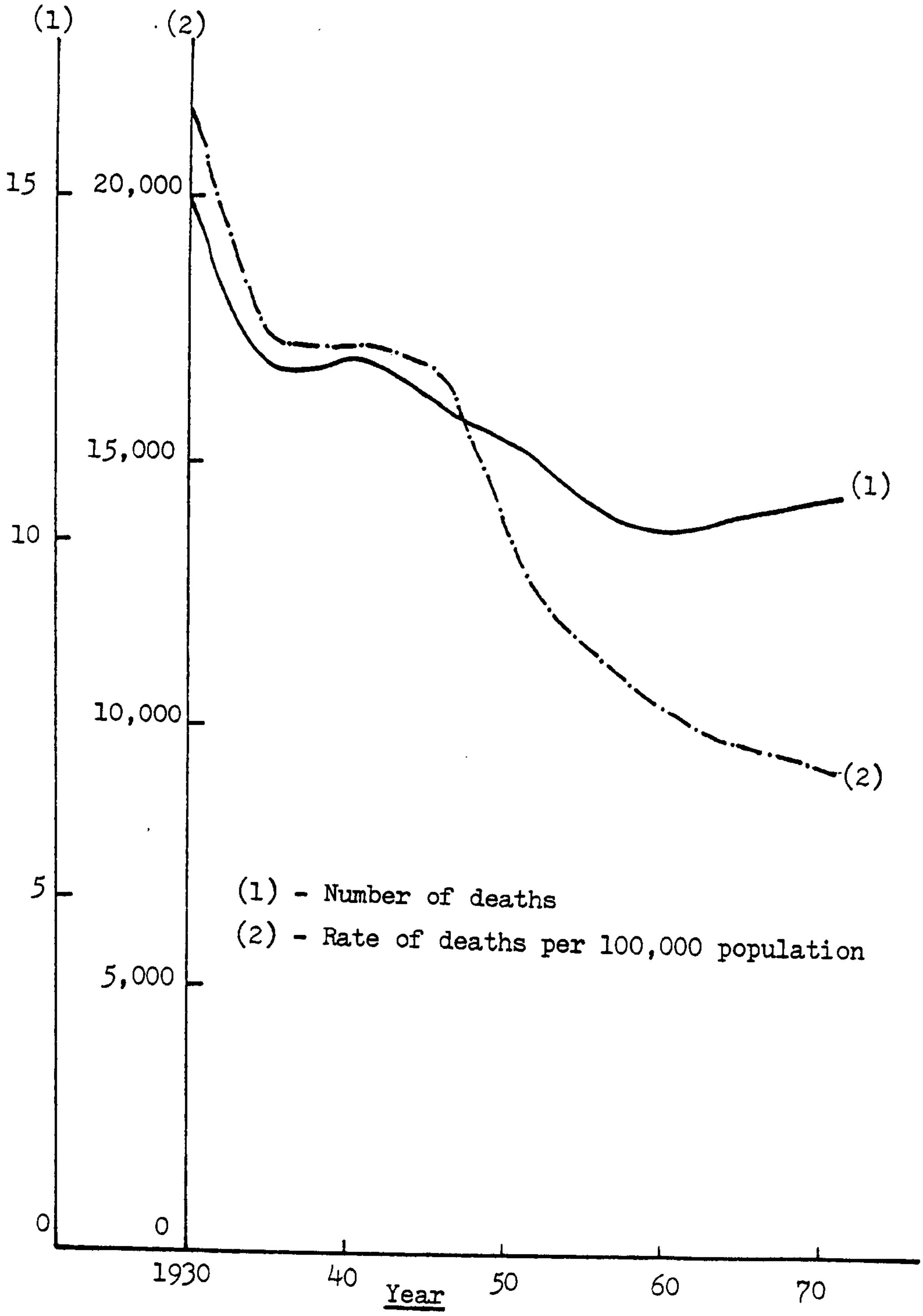


Figure (5) : Accidents in the U.S.A.
Source: National Safety Council, U.S.A.

1.35 Management of Safety

Safety has now become one of the most important goals of any organization. Theories have evolved to discuss, and techniques have been devised to control and manage, safety. Petersen [108] discusses the five principles of safety management in detail. These are outlined below:

1. An unsafe act, an unsafe condition, and an accident are all symptoms of something wrong in the management system.
2. We can predict that certain sets of circumstances will produce severe injuries. These circumstances can be identified and controlled.
3. Safety should be managed like any other company function. Management should direct the safety effort by setting achievable goals and by planning, organising, and controlling to achieve them.
4. The key to effective line safety performance is management procedures that fix accountability.
5. The function of safety is to locate and define the operational errors that allow accidents to occur. This function can be carried out in two ways:
   - (i) by asking why accidents happen - searching for their root causes.
   - (ii) by asking whether certain known effective controls are being utilized.

To manage safety, a safety policy should be devised for any organisation in order to affirm long-range purposes, commit management at all levels to reaffirm and reinforce this purpose in daily decisions and to indicate the scope left for discretion and decision by lower level management.

A safety policy today should include management's intent, the scope of activities covered, responsibilities, accountability, staff safety assistance, safety committees, authority and standards.

2. COAL MINING : THE BACKGROUND

2.1 COAL

2.11 Formation of Coal

Coal and peat are thought to be the remains of vegetation that grew on wet land such as swamps, bogs and marshes. When the vegetation died, it fell into the swampy environment and was transformed under anaerobic conditions into peat. The transformation of peat into coal proceeds by a sequence of geological processes. First of all, the peat deposit becomes covered with sand and silt, thus bringing to an end the biological processes of peat formation. Over the course of time, the thickness of sediments increases by deposition of further sand and silt and the peat is subjected to rising pressure. Water and volatile components are expelled, and the remaining material becomes relatively impoverished in oxygen and richer in carbon. Hydrogen ceases to be combined with oxygen as water, and instead becomes attached to carbon, forming hydrocarbons. This process which may take millions of years, eventually transforming the spongey, fibrous peat into hard and brittle coal.

2.12 Chemistry of Coal

The chemistry of coal can be summarized approximately by describing it as a hydrocarbon material deficient in hydrogen. Such description, however, is an oversimplification, and a fuller one is illustrated in Table 2.

		Peat		Lignite		Sub bituminous		High-Volatile bituminous		Low-Volatile bituminous		Semi-anthracite		Anthracite	
Ash-free, dry	Moist	91.20	71.14	35.96	31.06	23.93	16.04	14.08	13.99	3.20	9.50	5.19	5.81	3.33	2.70
	Ash	0.35	7.41	7.75	7.88	6.07	11.53	10.96	14.32	5.87	28.06	14.01	17.04	9.12	5.83
	Volatile	75.11	48.44	56.71	45.32	51.07	43.34	47.48	41.01	20.50	21.17	12.98	16.25	3.73	3.63
	F. Carbon	20.91	25.88	43.29	54.68	48.93	56.66	52.52	58.99	79.50	78.83	87.02	83.75	96.27	96.37
	Hydrogen	5.23	3.67	4.51	5.04	5.47	5.23	5.35	5.31	4.93	3.82	3.97	4.48	3.09	3.25
	Carbon	56.82	45.77	73.61	73.21	72.83	78.83	78.03	79.76	88.45	82.39	89.64	88.91	92.91	93.34
	Nitrogen	1.48	1.66	2.15	1.48	1.54	1.60	1.20	1.55	1.39	1.36	0.63	2.16	0.91	1.22
	Oxygen	32.26	19.58	17.69	18.66	18.99	14.31	9.73	10.16	3.84	6.75	3.23	3.97	2.41	1.32
	Sulphur	0.23	3.64	2.04	1.61	1.17	0.84	5.69	3.22	1.39	5.68	2.53	0.48	0.68	0.87
	MJ kg^{-1}	22.5	18.1	29.2	30.0	29.3	31.9	33.3	33.5	36.6	33.0	35.9	35.5	35.5	35.9

(Modified from Raistrick and Marshall (1938).)

Table 2 Composition of Different Types of Coal

As well as these major constituents of coal there are numerous minor ones, which are often present in remarkably large amounts. Table 3 shows the average amount of some elements in coal ash, together with the average content in the Earth's crust.

Element	Average content in coal ash (g tonne $^{-1}$)	Average content in Earth's crust (g tonne $^{-1}$)	Factor of enrichment
B	600	10	60
Ge	500	1.5	330
As	500	1.8	280
Bi	20	0.2	100
Be	45	2.8	16
Co	300	25	12
Ni	700	75	9
Cd	5	0.2	25
Pb	100	13	8
Ag	2	0.3	20
Sc	60	22	3
Ga	100	15	7
Mo	50	1.5	30
U	400	2.7	150

From B. Mason (1966).

Table 3 Minor Elements in Coal Ash

Looking at the table from a negative viewpoint, one would be worried by the existence of such poisons as arsenic, mercury, cadmium and lead, and the radioactive element of uranium. A more positive viewpoint, on the other hand, would emphasize the mineral wealth to be found in coal ash, and to wonder if extraction of such valuable elements as germanium might be economically worthwhile.

2.2 USES OF COAL

During the Nineteenth century, coal was the sole important source of fuel for industrial processes in Great Britain, and of high significance in many other countries. Figures 6 and 7 show the pattern of fuel consumption in Great Britain and the United States since 1850.

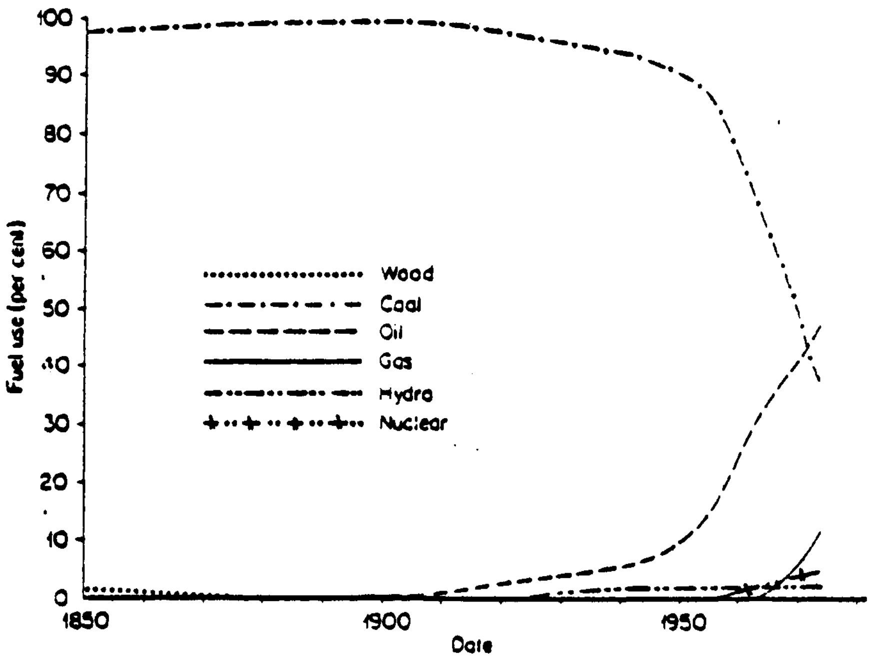


Figure 6 - Pattern of fuel use in the U.K. from 1850 (reproduced from reference number 110)

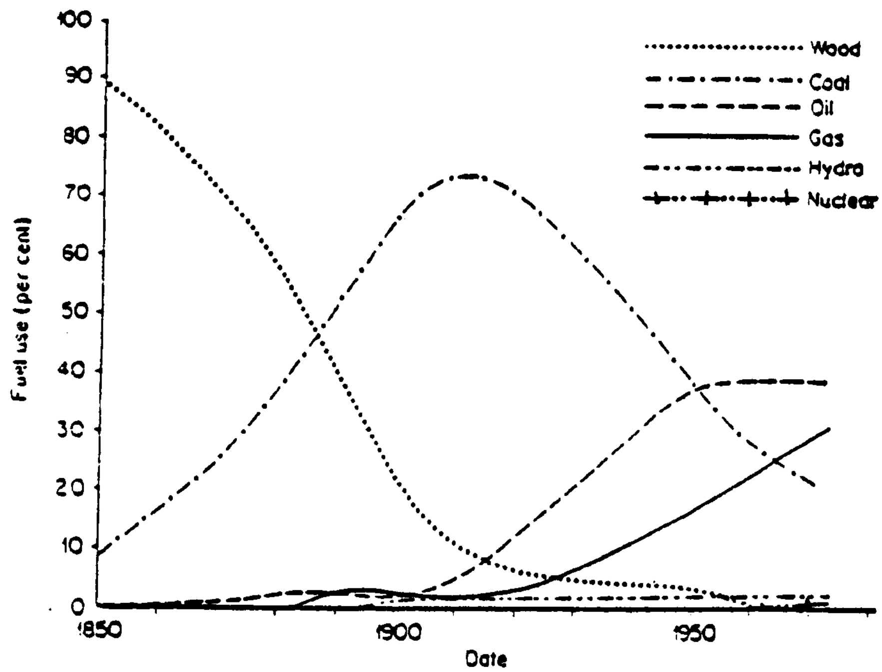


Figure 7 - Pattern of fuel use in U.S.A. from 1850
(reproduced from reference number 110)

Although coal was challenged by oil in the twentieth century, it by no means lost its important role as a source of energy. The uses to which coal is put have changed considerably over the years. These uses together with their variations are listed in Table 4.

The following conclusions can be drawn from the Table:

1. Electricity generation has now become by far the most important use of coal and the tonnage increased steadily until recently, despite competition from oil. This can be explained by the fact that electricity is the most convenient form of energy, while solid fuel is usually the least.

2. Coal gasification reached a peak of consumption in the mid 1950's and then decreased, as it was being replaced by oil and natural gas. The North Sea gas fields are expected to become exhausted much sooner than the British coal reserves, and therefore it is possible

that coal will be used for this purpose again.

3. Although the tonnage of coal used for coke ovens shows a decline, this indicates high efficiency in the use of coke rather than a decrease in steel production.

4. Collieries which used their own coal for mining operations have now replaced it mainly by electricity.

5. The use of coal for locomotives and marine bunkers has ceased, replaced by oil and electricity.

Diversification of the uses of coal has been the subject of much research, mostly, in the U.K., by the National Coal Board. In September 1980, the spokesman of the Board[111] announced that the research work in turning coal into oil had been successfully completed and tested, and by 1990, this type of oil will be in full production. It is asserted that 50 gallons of petrol and 80 gallons of other oil can be produced from each tonne of coal.

Skea[112] has forecast in 1980, the amount of coal used for different purposes in the future until after the year 2000. Figure 8 shows his conclusions, with more tentative forecasts beyond 2000 A.D. Recent economic effects, however, cast doubt on his figures.

Year	Supply (Total)	Electricity	Gas	Coke Ovens	Collieries	Railways	Other Industries	Domestic	Miscellaneous	Export	Overseas Marine Bunkers
1923	281.5	7.3	17.5	20.1	17.2	14.2		103.6		80.6	18.4
1924	268.9	7.8	18.4	19.2	16.9	14.4		109.5		62.5	18.0
1925	247.4	8.2	18.1	16.7	15.6	14.3		104.2		51.4	16.8
1926	151.8	8.4	17.6	7.2	7.7	12.3		69.0		20.8	7.7
1927	255.1	9.1	18.8	17.7	14.8	14.5		109.1		51.7	17.1
1928	241.7	9.4	18.6	17.7	13.7	14.0		98.6		50.7	17.0
1929	262.1	10.0	18.9	20.3	13.9	14.3		104.7		61.1	16.7
1930	246.1	9.9	18.7	17.5	13.7	13.8		99.0		55.6	15.8
1931	220.1	9.8	18.4	12.9	12.8	13.2		92.9		43.2	14.8
1932	212.9	10.0	18.0	12.9	12.2	12.6		91.4		39.3	14.4
1933	212.0	10.5	17.7	13.3	11.8	12.6		91.1		39.4	13.6
1934	224.2	11.4	18.2	17.2	11.9	13.1		96.6		40.0	13.7
1935	227.4	12.4	18.3	17.7	11.8	13.2		100.1		39.0	12.7
1936	232.2	13.8	19.4	20.4	12.0	13.7		103.4		34.8	12.2
1937	244.8	15.0	19.7	22.3	12.4	14.0		106.4		40.7	11.9
1938	227.7	15.1	19.4	19.4	12.1	13.4		99.2		36.2	10.7
1939	236.6	16.2	19.2	20.7	12.3	13.1		105.7		37.3	9.8
1940	228.6	18.4	18.1	22.7	12.5	13.7		111.0		19.8	7.1
1941	210.7	20.7	19.4	21.4	12.3	14.0		109.3		5.2	4.4
1942	208.4	22.7	21.0	21.9	12.2	14.7		105.6		4.4	3.6
1943	200.6	23.0	21.1	21.2	11.8	15.0	43.1	39.6	16.0	4.9	3.3
1944	194.9	24.5	21.0	20.4	11.3	15.2	40.2	37.6	17.5	3.8	2.4
1945	187.2	23.9	21.3	20.4	10.7	14.8	37.0	35.6	16.1	5.6	3.1
1946	194.2	26.6	23.1	20.4	10.8	15.0	35.9	38.6	16.4	4.2	4.8
1947	201.5	27.5	23.1	20.1	11.2	14.5	36.4	36.6	15.5	0.9	4.5
1948	211.2	29.3	25.0	22.7	11.4	14.5	37.0	38.6	16.2	10.9	5.5
1949	218.2	30.5	25.7	23.0	11.0	14.6	36.6	38.9	16.2	14.3	5.2
1950	220.4	33.4	26.6	23.0	10.9	14.4	37.9	40.7	16.3	13.1	4.1
1951	227.6	36.0	27.8	23.8	10.8	14.3	37.7	41.6	16.4	7.8	3.8
1952	225.6	36.1	28.1	25.5	10.5	14.1	37.4	39.5	16.3	11.8	3.4
1953	230.4	37.3	27.5	26.3	10.1	13.6	37.7	40.0	15.8	13.9	2.9
1954	231.2	40.2	27.7	27.0	9.7	13.2	38.8	41.5	16.4	13.7	2.5
1955	236.1	43.6	28.3	27.4	8.8	12.4	37.7	41.4	16.2	11.9	2.2
1956	230.6	46.3	28.2	29.8	8.0	12.3	38.1	40.1	15.3	8.2	1.6
1957	224.9	47.1	26.8	31.2	7.3	11.6	36.2	38.1	15.1	6.8	1.2
1958	209.4	46.8	25.2	28.2	6.6	10.5	36.8	34.2	14.5	4.1	0.9
1959	194.0	46.7	22.9	26.1	5.7	9.7	33.9	32.2	12.7	3.7	0.7
1960	204.4	51.9	22.7	29.0	5.1	9.0	35.0	31.8	12.7	5.3	0.3
1961	203.0	55.6	22.6	27.2	4.6	7.8	32.9	29.7	11.9	5.7	0.1
1962	198.6	61.4	22.5	23.9	4.3	6.2	33.2	27.8	12.4	4.8	0.1
1963	206.2	67.9	22.5	23.9	4.0	5.0	32.5	26.3	12.5	7.6	
1964	197.2	68.5	20.5	25.9	3.8	3.9	28.3	25.1	11.9	6.1	
1965	190.5	70.4	18.3	26.1	3.5	2.8	27.7	24.5	11.7	3.8	
1966	182.0	69.0	17.0	24.7	3.1	1.7	25.9	22.6	11.0	2.8	
1967	177.6	68.3	14.8	24.0	2.9	0.8	23.3	20.8	10.8	1.9	
1968	169.9	74.4	10.9	25.3	2.4	0.2	23.0	20.3	9.7	2.7	
1969	155.7	77.1	7.0	25.7	2.0	0.2	21.7	19.0	9.0	3.6	
1970	147.1	77.2	4.3	25.3	1.9	0.1	19.6	17.5	8.8	3.3	
1971	149.5	72.8	1.8	23.6	1.6	0.1	15.8	14.7	7.5	2.6	
1972	121.8	66.6	0.6	20.4	1.4	0.1	11.7	12.3	6.4	1.8	

Derived from U.K. Energy Statistics 1973, Department of Energy. 1973 and from Statistical Digest. 1966. Ministry of Power, 1966.

Table 4 Different Uses of Coal 1923–1972 (Million Tonnes)

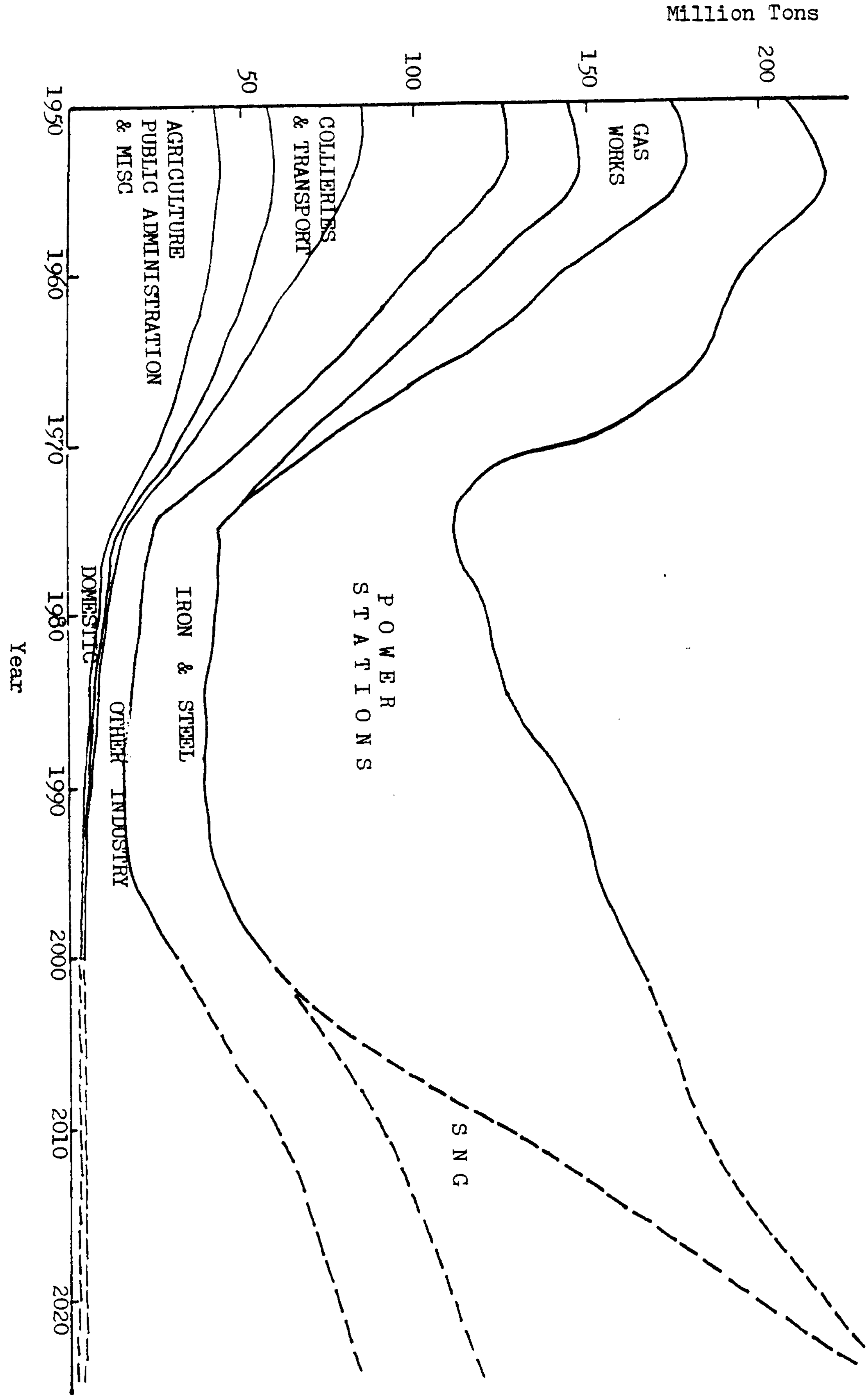


Figure 8   Reproduced from reference 112

Demand for Coal

2.3 HISTORY OF COAL MINING

The history of the modern industrial world is largely based on coal. Man has mined and used coal for about 3000 years; the Chinese are said to have used coal in 1000 B.C.[110].

There is evidence to prove that coal was worked during the Roman occupation of Britain, but as there are few references to coal in the writings of classical authors, this can not have been of great importance in the economy of Roman Britain.

It can not be said whether coal was used or not during the Dark Ages. If, however, it was, it must have been of little importance again, since it is not mentioned in the Domesday Book.

There is no doubt nevertheless that coal was worked in many places in the twelfth century. Coal became important in the sixteenth century when the price of timber rose rapidly.

In the early stages of coal mining (if it can be called 'mining'), it was only worked on outcrops (coal was picked up where it lay).

By the twelfth century, coal was being got in small quantities and shallow ditches and in the thirteenth century, in addition to some opencast methods, coal was being won from shallow drifts and bell pits.

Where seams lie deeper than about 20 feet, bell pits are intolerably wasteful of labour. The practice therefore developed of heading out into the seam for a short distance on each side of the shaft. Between the headings the wide pillars of coal were usually strong enough to hold up the roof, although wooden props were no doubt occasionally used.

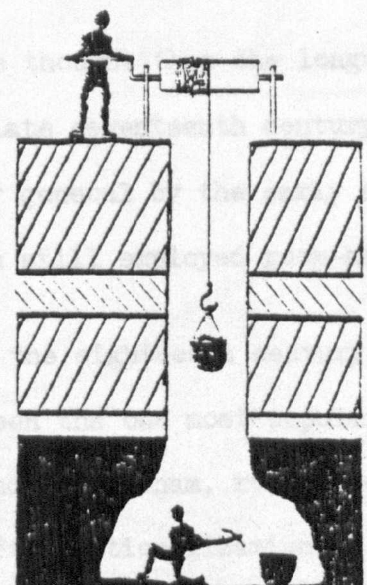


Figure 9 - Bell pits with windlass
(From reference number 114)

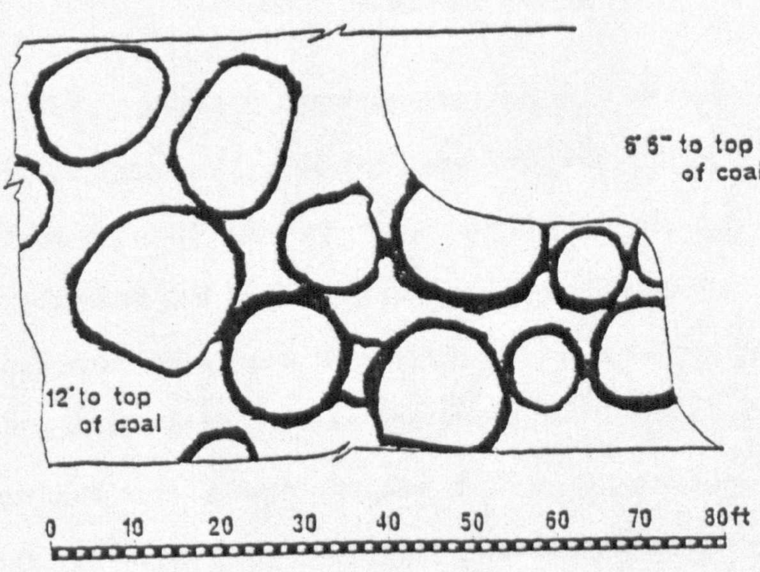


Figure 10 - Bell pits in Derbyshire
(from reference number 114)

The room-and-pillar system of mining was established in the fifteenth century or earlier[113]. This system although ideal for conditions of work at that time, was almost entirely replaced by longwall methods later.

It is thought that the longwall method of working was first used in the late seventeenth century in Shropshire and the system became fairly general by the early eighteenth century, although the shallow mines still employed room-and-pillar.

From the eighteenth century to the present, the longwall method has been the one most popularly employed, although in Northumberland and Durham, room-and-pillar system was still adopted until well after nationalization. It is claimed that the reason for not changing to the new system was due more to reluctance to change than to particular geological conditions[114].

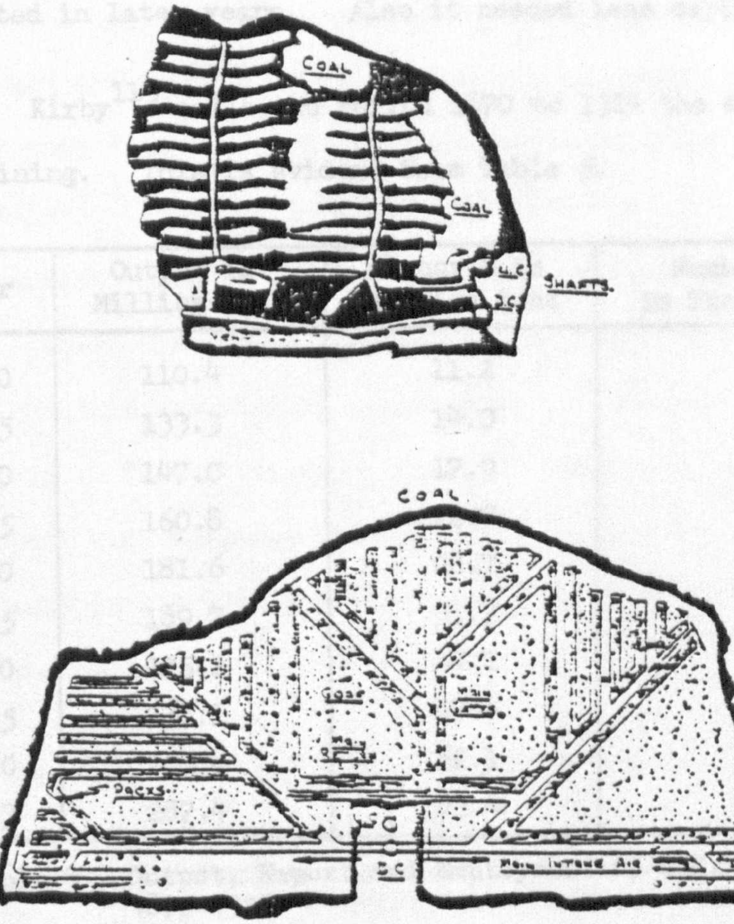


Figure 11 - Two systems of seventeenth and eighteenth century coal working (from reference number 114)

It is evident from the available literature that early room-and-pillar method allowed for less than half of the coal to be extracted despite the fact that seams were shallow. The extraction rate increased and smaller pillars were left where possible. Later the method so developed that pillars were no longer left permanently. From the shaft bottom first the rooms were extracted leaving larger pillars and coming back towards shaft, pillars were taken. This was a great improvement in coal mining methods for no longer were valuable reserves left unworked which would be almost impossible to be extracted in later years. Also it needed less capital expenditure.

Kirby[115] calls the period 1870 to 1914 the era of expansion of coal mining. This is evident from Table 5.

Year	Output in Million tons	Exports in Million tons	Number Employed in Thousands of men
1870	110.4	11.2	350.9
1875	133.3	14.0	535.8
1880	147.0	17.9	484.9
1885	160.8	22.7	520.6
1890	181.6	28.7	632.4
1895	189.7	31.7	700.3
1900	225.2	44.1	780.0
1905	236.1	47.5	850.4
1910	264.4	62.1	1,049.4
1913	287.4	73.4	1,127.9

Table 5 Output, Export and Employment in U.K. Coal Industry 1870-1913

Source: Abstract of British Historical Statistics, Cambridge 1962

During the period of World War I a growing pressure from the miners on the government of the day for the state ownership of the mines and mineral rights resulted in a Royal Commission being set up in 1916 "to investigate and make recommendations on the future operation of the mining industry". The report of the commission recommended that the mineral rights should be taken into state ownership.

From the early 1920's the so called "depression years" of the mining industry began. Governments attempted to correct the situation by many different actions.

On the other hand, the standards of safety were as Mr Justice

Sankey said "so that one would have good reason to be ashamed". The number and intensity of mining disasters convinced the government of the day that urgent action was required to make the mines safer places to work in. The Royal Commission of 1936 was set up with a comprehensive report[116] giving important recommendations in its 520 pages. This report also recommended the state ownership of mineral rights and this was finally implemented in 1942 with compensation being paid to former owners. Turner[117] states that as a result of this report some measures were introduced which led to a rapid improvement in the mining environment and a slow-down in the incidence of major disasters.

As the war progressed it became increasingly obvious that a central control of mines was required and this function was carried out by the Mines Department, until in 1943 a National Coal Board was set up. This Board continued to operate until 1946 when a Government committed to nationalization of the basic industries was returned to power and as a result on first January, 1947, the ownership of the mines passed to the state.

The industry became better organised, expert management services were provided, and capital was readily available through the Board's decisions. This resulted in the industry improving along many different lines, particularly from the mechanisation point of view, which will be dealt with later.

In the early 1960's, the mechanisation drive was continuing unabated. Coal was plentiful but so was oil. Changes were taking place in the affairs of other, nationalized, customers of the

National Coal Board. The British Railways dieselization and electrification policy was being rapidly introduced, British Gas was introducing new processes which produced gas more efficiently, and the re-organization of British steel manufacturing processes resulted in a severe falling off in home demand causing over-production and heavy stocking at collieries.

As a result pit closures took place and a good number of mines were closed down. The mass media had convinced themselves, and much of the nation, that the coal industry was in rapid decline and its total demise was just a matter of time. They had not however taken into account the rapid changes in world events - neither the changes in world energy demands, nor the events of the Middle East in the early 1970's.

The intervention of external international events in the cost and availability of fuels resulted in an advantageous reappraisal of the role of the coal industry and once again expansion began in the 1970's, and after less than one decade the yeilds are now beginning to be observed.

Modern collieries are now equipped with the most advanced devices, and coal faces are highly capital intensive, resulting in labour productivity and safety to be higher than ever before. Longwall methods of working and the use of shearer loaders, Armoured Flexible Conveyors, and powered supports are now predominant. In face operations, automation and remote control are also in their experimental stage.

3. TECHNOLOGICAL CHANGE IN COAL MINING

3.1 GENERAL

There was little change in the technology of coal mining until fairly recently, considering the age of the coal mining industry itself. For as long as picks and shovels were used, and no other technological change had taken place, coal mining could not operate at any great depth or on a large scale.

The first means of supplying power was water, which was used in 1680, and after that steam came into use in 1705. Application of steam was diversified and rotary steam engines evolved in 1779. This was a major technological advance in coal mining and hence enabled shafts to become deeper. More collieries were opened so that in the year 1800 coal production was about 10 million tonnes. Attempts were being made to get the maximum use of the technology available at the time (mainly that of steam), and as a result progress was made in ventilation, pumping, winding and transport, thus increasing the national output to 100 million tonnes in 1865.

So far there has been no mention of technological progress at the coal face itself, which is the main topic with which this presentation is concerned. The reason is that there was no technological advance at the coal face until 1850. It is claimed by Griffin[114], that, because so much coal could be won either by the patchwork method or by drifts, there was no incentive and little opportunity to master the latest techniques. The few deep mines in existence by the mid-nineteenth century were therefore technologically backward.

It would perhaps be useful and interesting to mention technological constraints tending to hinder the production of coal at different times.

In the twelfth and thirteenth centuries problems of ventilation, drainage and winding limited the size of workings. These remained as the limiting factors until in about the middle of the eighteenth century when Newcomen engines for pumping were adopted, and therefore drainage was removed from the list of constraints.

The ventilation problem was also eased in the second half of the eighteenth century. At this time engines of sufficient power had been adopted to drive fans to ventilate mines.

In about 1800, steam winding engines were chosen to increase the shaft capacity. This objective was achieved, but not to remove the constraint completely. The winding problem was not solved until 1840 when cages could be held steady in the shaft by guide rods.

Having removed these constraints, underground transport then seemed to be the limiting factor. This problem was also becoming increasingly important because faces were getting further from the pit bottom. The first choice at that time would certainly be steam engines. Later compressed air engines, diesel engines and eventually electricity was used to drive haulage engines underground. The problem was, however, largely solved by the end of the nineteenth century.

It was only in the late years of the nineteenth century that the limiting factor of coal production was found to be at the coal face, rather than elsewhere underground. One should not, therefore, expect to see much improvement before then on the coal face. Two main reasons can explain this: firstly, the coal face had a higher inherent potential; and secondly, it is conceivable that at the same time as attempts were being made to remove other constraints, work was also being carried out to improve the technology at the coal face, so that this constraint was realised so late.

From the early twentieth century a great deal of effort has been spent at the coal face to remove this constraint. Although largely eased but it can be argued that it is still a limiting factor today.

In the twentieth century a long list of constraints appeared but none as severe as those of the earlier times. Lack of safety was one, eased by legislation. Transport, once again, eased by the adoption of belt conveyors, the Armoured Flexible Conveyor (AFC), high speed manriding trains etc. Ventilation problems which tended to slow the rate of face advance, were eliminated by the use of efficient fans and methane drainage systems. The list is an endless one. Regarding the coal face, after the development of powered supports, modification of the shearer loader, and adoption of the A.F.C., the rigid cycle production system was replaced by a continuous one. Since 1970, coal faces are particularly highly productive, and if no constraint were present, they would have produced far more than they do. The limiting factor now, as it is claimed by mining engineers, is that of the coal face ends, slowing the rate of advance and therefore the production rate.

Perhaps the greatest change in mining practice has been the adoption of electriicty, but it has rarely been regarded as technological change since its adoption took place gradually. This is explained by the fact that it happened before nationalisation, when colliery owners simply waited for others to try electricity to observe the results and little experiments and research work by colliery owners were being done.

Electricity as a source of power was first used in U.K. coal mines during the 1880's, and in a few decades generated great enthusiasm amongst mining engineers. Holliday[118] in his paper presented to the Institution of Mining Engineers in 1904 (when he compared 3-phase and continuous-current electricity for mining purposes) apologised for yet another paper about electricity, commenting that not many years ago it was new to mining engineers, but things had changed so much that the meetings of the mining institution might be mistaken for meetings of the Institution of Electrical Engineers!

The first use of electricity underground was probably at Earnock colliery, Scotland, in 1881 when electrical lighting was tried on a coal face, but the first application for underground active power was at Trafalgar colliery, Forest of Dean, in 1882[119, 120] when Sir Francis Brain installed a 3-Kw motor to drive an underground pump. Several installations, principally for pumping and haulage, quickly followed in the course of a few years, but it was not until

1910 that the first all electric colliery, the Brittania (Monmouth), was opened [121]. The adoption of electricity then became so rapid that from 1912 to 1937 the total Kw used by collieries had been quadrupled. From then most of the effort spent was to increase power, to modify and diversify the equipment to cope with different situations, to increase flexibility and to reduce the danger associated with their use. It is now not uncommon for a modern face to be equipped with machinery totalling over 1000 Kw and it is fairly safe to assert that almost every apparatus used in a modern colliery is somehow electrically powered.

Nationalisation of the U.K. coal industry was carried out in 1947, after which the picture of the industry has been somewhat different. Since then virtually every aspect of the coal face has received attention with a view to increasing efficiency and productivity. Particular attention has been given to coal getting and loading machinery and a wide diversity of machines have been designed, installed, modified and in some cases rejected. Other operations at the coal face, such as transport and support systems, have also been radically changed. Face conveyor design today is based almost entirely on the A.F.C. whose use has made the system of mining much more flexible and potentially highly productive, since it enables coal production to be continuous as opposed to intermittent.

The main objectives of the Board from mechanisation of coal faces can be summarised as: to increase productivity, to increase or maintain bulk output, to reduce total cost, to improve safety and health and to reduce the hardness inherent to face work. From what has been explained in earlier chapters, it is apparent that the Board has been successful only in achieving some of these objectives; and in some cases such as the bulk output, the result has been opposite to the aim.

Coal faces are now, once again, equipped with conventional machinery and methods. The longwall system of mining is predominant and the use of powered supports, the shearer loader and the A.F.C. is almost certain at any coal face. Little technological change has taken place since the early 1970's and improvements have been confined to coal face environment and modification of pre-existent equipment. For this reason, coal face productivity and safety have not changed much. However, the more centralised and sufficiently financed research efforts by the N.C.B. are so objective orientated that the likelihood of invention and innovation of a major technique or machinery is enhanced.

The N.C.B. seems to be well aware of this, as is apparent from the statement made by Sir Derek Ezra, the then chairman of the Board. In effect he said: "We know what we are aiming for at the moment in terms of our research efforts, but mining will undoubtedly change. How will it change towards the end of the century and beyond? What new techniques and devices will be employed? If we can guess at them now then we ought to be instituting immediately the research that will bring them to fruition in due course". Sir Derek Ezra emphasized that he was not thinking of "evolutionary" but of "revolutionary" technologies. Evans[122], analysing these statements asserts that technological change can be forecast in terms of known knowledge, but technological revolution is quite unpredictable, and he goes on by saying that, if there is anything new, it is more likely to be found outside the coal industry.

As a result of the above statement by Sir Derek Ezra a small group of scientists and engineers was commissioned to study techniques which might have relevance to coal mining into the period beyond A.D. 2000. A summary of the report submitted to the Board is given in the paper by Evans[122] which gives a full but brief account of the probable future technological change in the mining industry.

To summarize the nature of technological change in the coal industry after nationalisation, it has been divided into nine categories that were listed in Chapter 1.11(P 2).

In 1974 the N.C.B. announced its intention to proceed with a programme of Advanced Technology Mining to follow on from the mechanization initiative first launched in the 1950's. In this programme particular attention has been given to automation of the coal face. The detailed programme is explained and justifications produced with the help of actual examples by Bourne[123] .

From what has been said, it is safe to assert that two major technological revolutions have occurred in the mining industry, the first in the period of 1840 to 1860, and the second between 1950 and 1970.

3.2 CONSEQUENCES OF TECHNOLOGICAL CHANGE

Technological change has undoubtedly had great influence, on coal mining, as on other industries. Two effects, concerned here, and perhaps the most important ones, are on productivity and safety. It was indeed intended to do so, as one of the objectives of the N.C.B. at the time of foundation was to provide means so that technology would improve with particular attention to productivity and safety.

It is evident that technological change has had the greatest influence on safety, by invention of new machinery , techniques and methods.

Technology also tends to improve morale, as has been proved statistically by Harper and Kalton[124] , where they concluded that morale is dependent upon the degree of mechanisation, among other things. Morale itself, although being a part of health and safety, further tends to improve the actual physical safety (this has been discussed earlier). A disagreement with this by Revan[125] shows that morale and the size of an organisation move in opposite directions, and in the U.K. it is usually the case that larger mines are also more mechanised too.

The significance of technological change in improving both productivity and safety has been noted and documented by many authors including Gold[126], Rosenberg[127, 128], Taylor[129], Mansfield[130, 131] and Thomas and Cooper[132] who showed this by a few statistics. They divided the coal faces into three groups in order of the degree of mechanisation as follows.

Method of Working	Accidents per 100,000 Manshifts Worked	Accidents per 10^6 Tonnes of Coal Mined
Hand filled, hand set supports	1.60	2.70
Power loaded, hand set supports	1.45	2.00
Power loaded, powered supports	0.84	0.50

Table 6 Classification of Accidents According to Technology (from reference 132)

Christenson and Andrews[133] used the model:

$$I = f\ (T,\ S,\ R)$$

Where I is the injury rate
T is the technology adopted
S is the typical size of mine
R is the government regulatory activity,

to study safety in coal mines. They expanded the model, tested it by actual data from the United States, and concluded that in the period since World War II, technology has brought about a lower risk of accidental injury in underground coal mines. Before this period, however, they comment that the opposite could have been the case.

Tregelles[134] attributes the recent improvements in safety to technological change. His conclusions are illustrated in Figure 12.

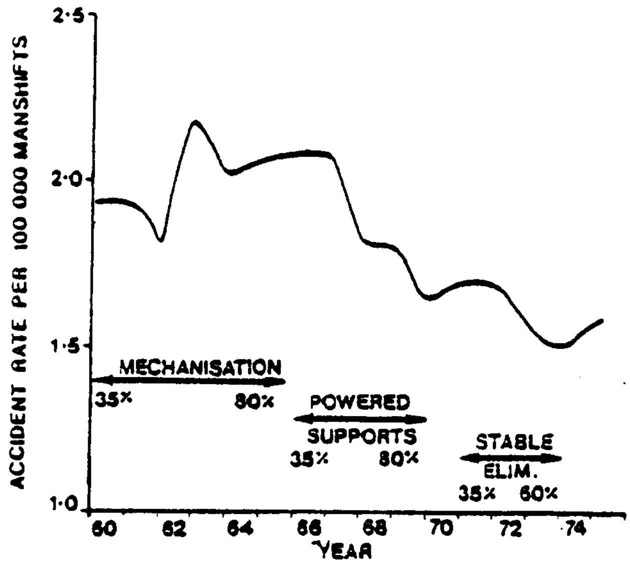


Figure 12: Fatal and Serious Accidents at the Coal Face (from reference 134)

From what was explained fully in earlier chapters, the influence of technological change on productivity is obvious. It was seen that economists have frequently tried to quantify the rate of technological change by productivity improvements, implying that technological change has directly affected productivity (see section 1.14).

Overall output per man year in the U.K. coal mines increased from 266 tonnes in 1947 to 469 tonnes in 1979[135]. A major part of this improvement should be attributed to technological developments. Unfortunately statistics regarding coal face productivity have only been produced since 1979/80 and since for any examination statistical information is required, this is postponed to later chapters where attempts will be made to extract the information required.

3.3 TECHNOLOGICAL CHANGE AT THE COAL FACE

3.31 Coal Cutter/Loaders

As already mentioned almost no attention was given to coal face mechanisation until about 1850. At this time the first technological advance occurred at the coal face, this being the introduction of compressed air. In 1853 the first compressed air coal cutter was taken to the face. Several different and some similar machines were invented after this time, many of them rejected. In 1856 a bar machine was introduced and in 1861 a type of disc machine was first put into trial. So far these machines had no significant success, but led to the invention of the Gartsherrie chain cutter used in a Scottish colliery in 1864.

The developments were relatively rapid so that as early as 1905 the report of the Royal Commission on Coal Supplies and Resources stated: "There seems to be no doubt that coal cutting machines are now firmly established".

In the early years of the twentieth century, attention was also being given to face conveyors, but it was apparent that it could not be developed as fast as the cutting machines. Also in these years, electricity was being increasingly used instead of compressed air and steam. The first cutter known to have been powered by electricity was used in 1885, and many other machines were introduced after this time. Early electrical cutters were both troublesome and dangerous, but from the early stages, the potential was realised and gradually they became firmly established.

From the mining methods point of view also, these years saw a change, so that longwall methods became more attractive, and in particular, the advancing longwall method was rapidly replacing the room-and-pillar method.

From the year 1864 until about 1920 a great number of new machines were invented, some of them did not even get away from the drawing table, some were put into trial, some were rejected, and some of them were modified or accepted for use. It was also at this time that coal cutters were spread over all districts. Although these cutters varied greatly from each other, they were almost all compressed air powered.

It was in the late nineteenth century that the potential for very high output and productivity, as tons per manshift, was realised; but although by the end of the century mining engineers had known this for a few decades, and so many machines had been invented, the innovation of these took such a long time that only about 1.5% of the national output was mechanically cut. This grew so rapidly that it increased to about 7% in 1910.

The great number of machines invented by 1920 had to be rationalised, and this is almost the only thing that happened between then and the second World War. There was no revolutionary type of machine, as occurred earlier, but the existing machines were modified and expanded. The output achieved by mechanised faces increased rapidly in this period, and by 1940 more than 140 million tonnes of coal was being mechanically cut and conveyed each year.

All these are apparent from the graphs in Figure 13.

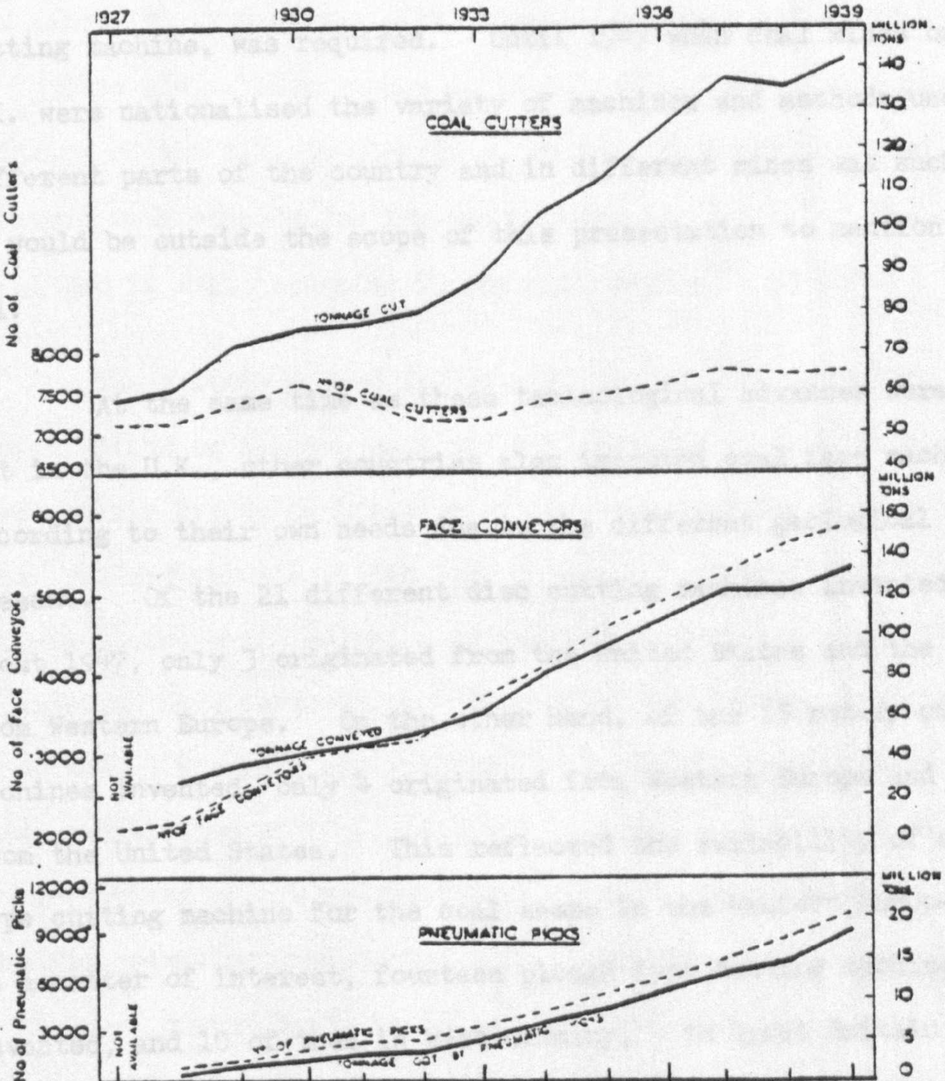


Figure 13: Number of Machines and Tonnage Cut, Face Conveyed and got by Pneumatic Picks.
(from reference number 116)

It was only after 1940 that continuous coal getting was considered. For this to be achieved, a type of flexible face conveyor, together with suitable supports and a more continuous cutting machine, was required. Until 1947 when coal mines of the U.K. were nationalised the variety of machines and methods used in different parts of the country and in different mines was such that it would be outside the scope of this presentation to mention them all.

At the same time as these technological advances were carried out in the U.K., other countries also improved coal face machines according to their own needs due to the different geological situations present. Of the 21 different disc cutting machines invented until about 1947, only 3 originated from the United States and the rest came from Western Europe. On the other hand, of the 15 rotary cutting machines invented, only 4 originated from Western Europe and the rest from the United States. This reflected the suitability of a disc type cutting machine for the coal seams in the Western Europe. Also, as a matter of interest, fourteen plough type cutting machines were invented, and 10 of them in West Germany, 3 in Great Britain and 1 in Austria. On the whole Britain seems to have kept pace with other countries until 1947 and of the total of 50 different cutting machines invented and innovated 13 (including the shearer loader which is now universally used) came from the U.K.[136]

Since 1947 much attention has been given to coal face mechanisation. It can be asserted that at that time coal face output with the existing technology had achieved its potential, and perhaps some major innovations were felt to be required.

In 1947 the coal industry was in a poor shape due mainly to the second World War, and total output fell from 227 million tonnes in 1938 to 184 million tonnes in 1945. The state of the coal industry of the U.K. is clearly shown and its inferiority as compared with other major European countries just after the second World War is well indicated in the Euhr Report[137] of 1974.

The perceived need for greater output, and therefore new mechanisation on the one hand and availability of capital brought about mainly by nationalisation of the coal industry on the other hand, yielded results within only a decade. Mechanisation of the coal face once again showed a marked improvement and a great number of machines were invented, put into trial and in many cases were innovated. Shepherd and Withers[136] claim that no visitor to the Essen exhibitions of 1950, 1954 and 1958 could fail to be impressed by the variety of new and experimental machines designed for specific operating conditions. This technological change resulted in the coal output being increased from 187 million tonnes/annum in 1947 to 210 million tonnes/annum in only a decade. This level of production was, however, reduced subsequently, but for reasons other than technological capabilities, such as pit closures, etc.

As a result of improved coal face mechanisation, the percentage of coal mechanically cut increased still further to 86% in 1955.

Table 7 illustrates the great number of machines which were in use in 1950's and 1960's. It is noticed that the types have narrowed down to only four and particularly in the case of the shearer loader it can be claimed that it dominates the picture today.

YEAR	A.B. Meco Mowe	Gloster Cutter	Plight Loader	Shearer Loader	Mawco	Trepan Shearer	Samson Stripper	Dosco Miner
1957	127	18	188	302	0	0	5	12
1958	115	15	181	294	0	0	6	11
1959	104	11	137	311	2	0	3	8
1960	102	9	112	326	10	1	3	10
1961	82	2	101	467	18	9	3	11
1962	42	0	84	565	12	30	2	9
1963	33		87	611	4	89	1	4
1965	10		79	723	0	110	1	2
1966	5		67	693		132	0	1
1967	0		0	706		122		0
1968				698		110		
1969				608		74		
1970				565		45		
1971				595		24		
1972				610		21		
1973				577		19		
1974				563		16		
1975				575		9		
1976				566		4		
1977				567		0		

Table 7 Different Face Cutting/Loading Machines Used After Nationalization

YEAR	Huwood Slicer	Trepanner	Rapid Plough	Scraper Box	Multi Jib Loader	Huwood Loader
1957	15	30	31	17	48	8
1958	24	72	50	15	33	28
1959	33	116	82	21	42	59
1960	32	175	142	23	38	51
1961	30	229	184	20	33	67
1962	20	245	179	15	37	57
1963	19	286	191	7	31	35
1965	16	288	168	2	41	15
1966	15	294	158	4	39	10
1967	12	280	134	0	0	0
1968	7	265	104			
1969	5	197	80			
1970	2	196	67			
1971	1	175	58			
1972	0	164	54			
1973		133	49			
1974		122	44			
1975		130	40			
1976		116	34			
1977		113	29			

Table 7 Continued

3.311 Anderton Shearer Loader

The shearer loader invented in 1952 by James Anderton, the N.C.B. mining engineer in Lancashire, has been one of the most important inventions in the coal industry since the World War II. It was this machine that made possible the integrated mechanisation of cutting, loading and conveying of the coal. In 1976, 75% of all British coal was cut and loaded by shearer loaders. It is indeed the biggest single royalty earning innovation for the N.C.B.

Although it was first invented as a revolutionary piece of equipment, it has been subject since then to extensive evolutionary modifications and improvements. Nowadays, although the principle of the machine has not changed, it hardly looks similar to the one invented in 1952.

Shearer loaders have now evolved into a family of machines, the major different types being: uni-directional; bi-directional; single ended ranging drum shearer; and double ended ranging drum shearer, suitable for virtually any condition. Its virtues are: reliability, flexibility under varying conditions, simplicity and cheapness.

3.32 Coal Face Conveyors

Coal cutters introduced in the late nineteenth century increased the production of each face and this increase in the output of the face was regarded as "in the mine output". This coal had then to be conveyed, and hand conveying and ponies could no longer cope with moving this output along the face. This was realised in the early twentieth century, but as there had already occurred a technological gap between coal cutters and conveyors, the number of conveyors used were always less than the number of cutters.

In 1902 the first face conveyor was invented which consisted of a trough running along the face. The second type of conveyor was a train of trays joined together, invented in 1908. In 1920 a form of shaker conveyor, and in 1930 the belt conveyor, came into action.

The above mentioned gap between coal cutters and conveyors, although initially a marked one, tended to narrow so that by 1940 almost all faces equipped with coal cutters also had a form of conveyor installed. In other words in 1939 61% of the total production was cut mechanically and 58% conveyed in this way. In 1940, 63.7% of the total production was cut and conveyed mechanically and in 1950, a higher percentage was conveyed mechanically than cut.

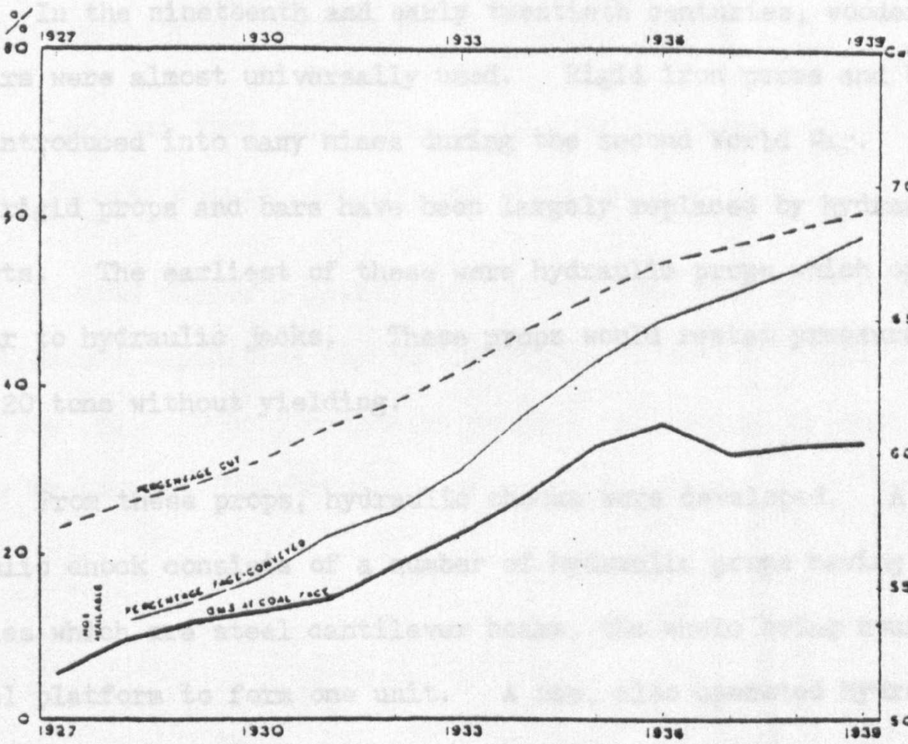


Figure 14: Output per Manshift at the Face and the Percentage of Output Cut and Face Conveyed (from reference number 116)

Dominating the picture today is the Armoured Flexible Conveyor. Its potential is as high as that for the shearer loader, as it is easily pushed forward by the powered supports to keep close to the cutting machine. As it can be bent in the form of a "snake", it would suit any method of working at the coal face.

3.33 Supports

In the nineteenth and early twentieth centuries, wooden props and bars were almost universally used. Rigid iron props and bars were introduced into many mines during the second World War. Since 1945, rigid props and bars have been largely replaced by hydraulic supports. The earliest of these were hydraulic props which operate similar to hydraulic jacks. These props would resist pressures of up to 20 tons without yielding.

From these props, hydraulic chocks were developed. A hydraulic chock consists of a number of hydraulic props having canopies which are steel cantilever beams, the whole being mounted on a steel platform to form one unit. A ram, also operated hydraulically, is attached to the platform to move the face conveyor.

It was only during the 1960's that self advancing high capacity powered supports became available. This enhanced the use of the longwall system of mining which was being restricted because reliable supporting equipment was not available. Since then longwall mining has become the predominant underground coal mining method in Europe. Experience has indicated that longwall is the most reliable and economical method for uniform, flat coal seams lying more than 500 metres below the surface. It has been successfully used under various geological conditions and for steeply inclined seams at depths up to 1300 metres.

The powered supports not only hold up the roof, push a conveyor or spill plates, and move forward themselves, but also provide a safe space for all necessary mining activities and contribute greatly to the success of longwall mining.

There are four main types of powered supports available now, namely: frames, chocks, shields and chock shields.

Powered supports have rapidly grown into many different types with different capacities (up to 800 tonnes or more at yield), dimensions (up to 4 or 5 metres in height) and design, so that they can now be adopted for virtually any seam conditions.

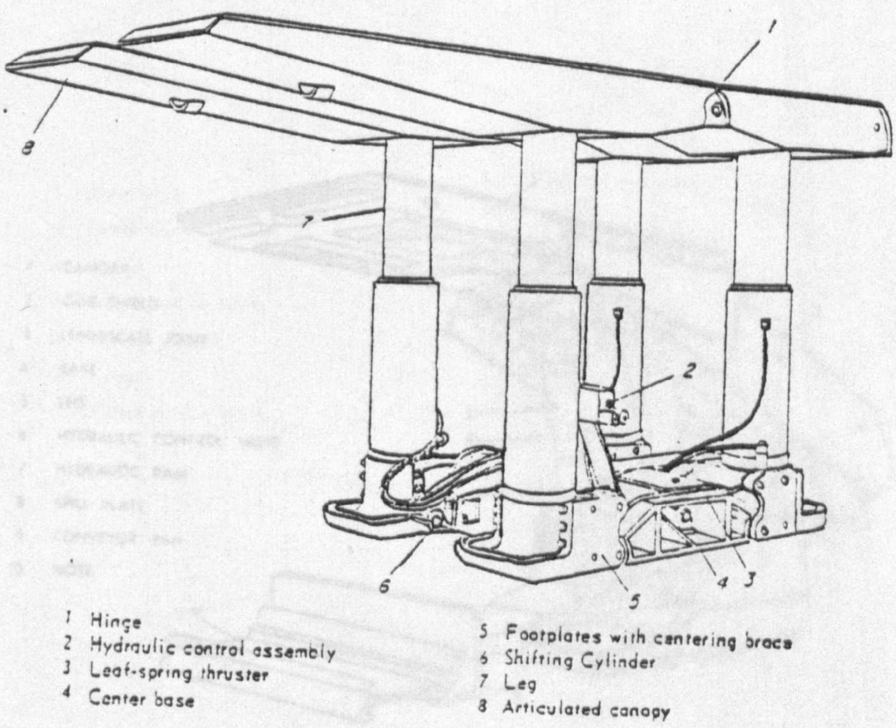


Figure 15: A Frame-Type Powered Support
(from reference number 138)

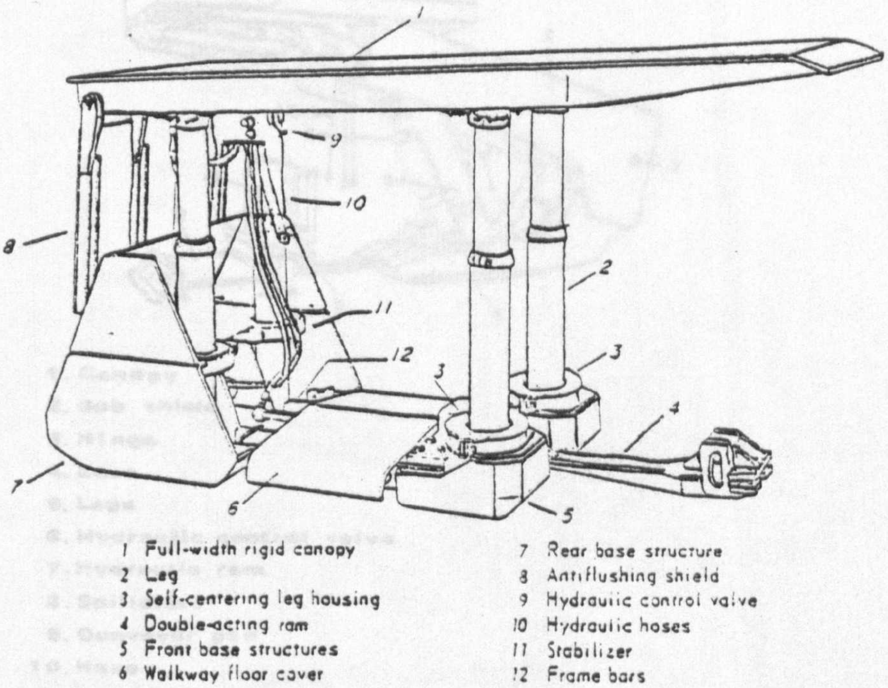


Figure 16: A Chock-Type Powered Support
(from reference number 138)

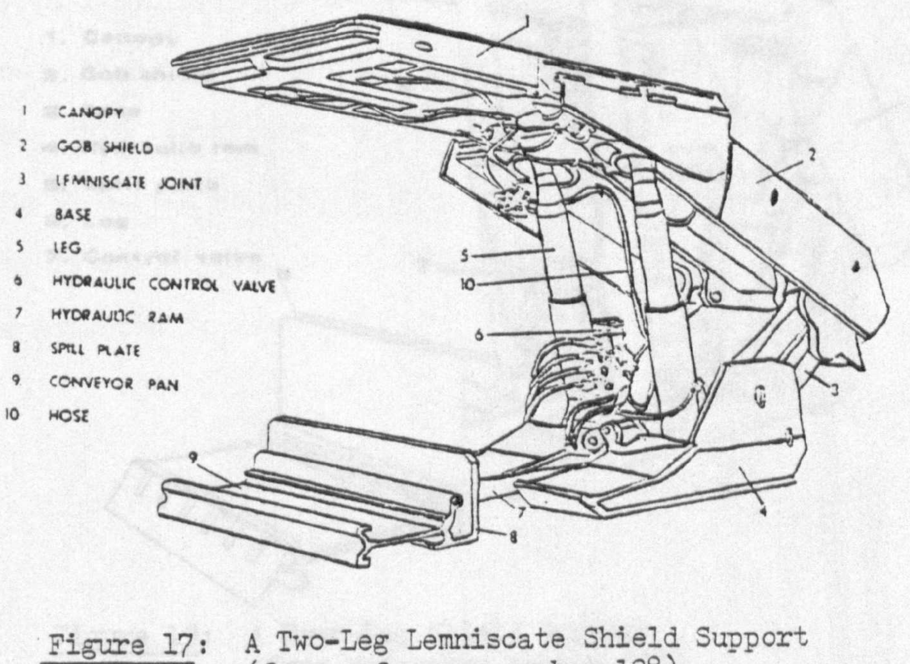


Figure 17: A Two-Leg Lemniscate Shield Support
(from reference number 138)

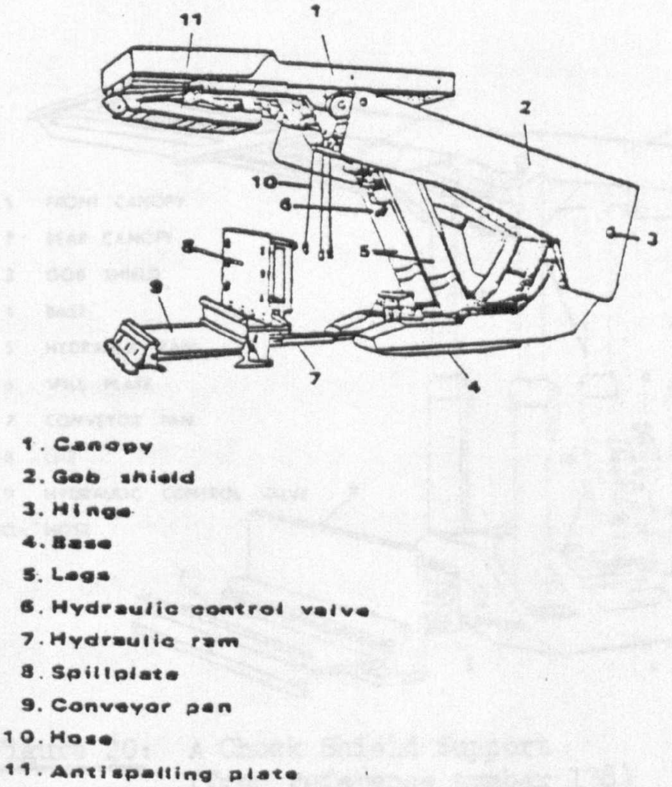


Figure 18: A Two-Leg Caliper Shield Support
(from reference number 138)

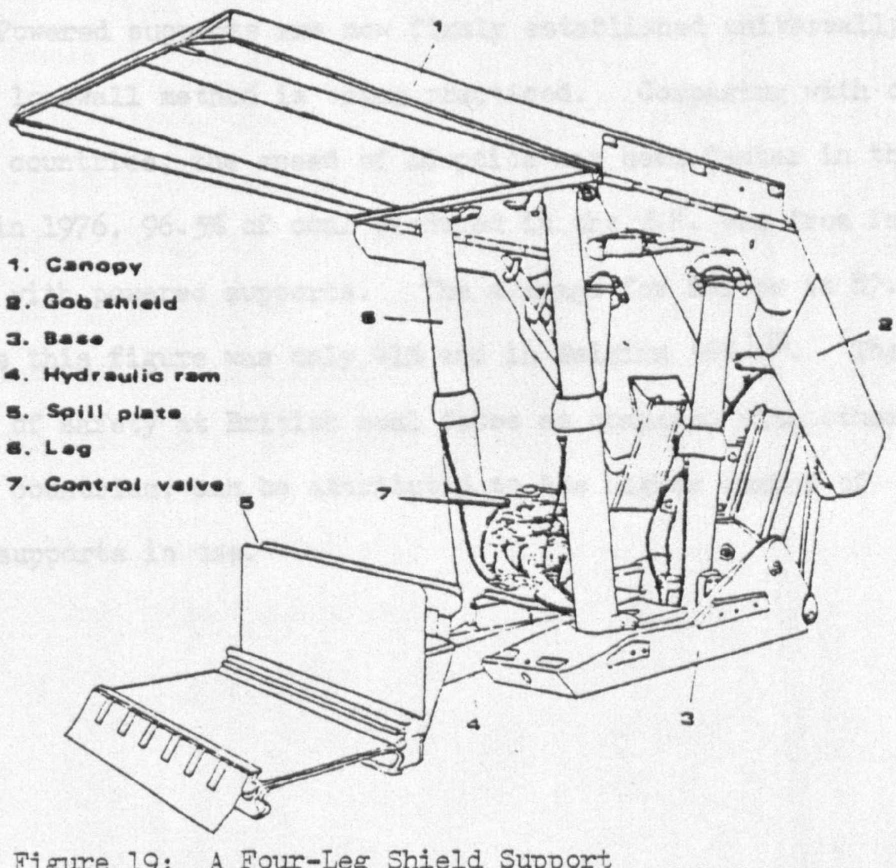


Figure 19: A Four-Leg Shield Support
(from reference number 138)

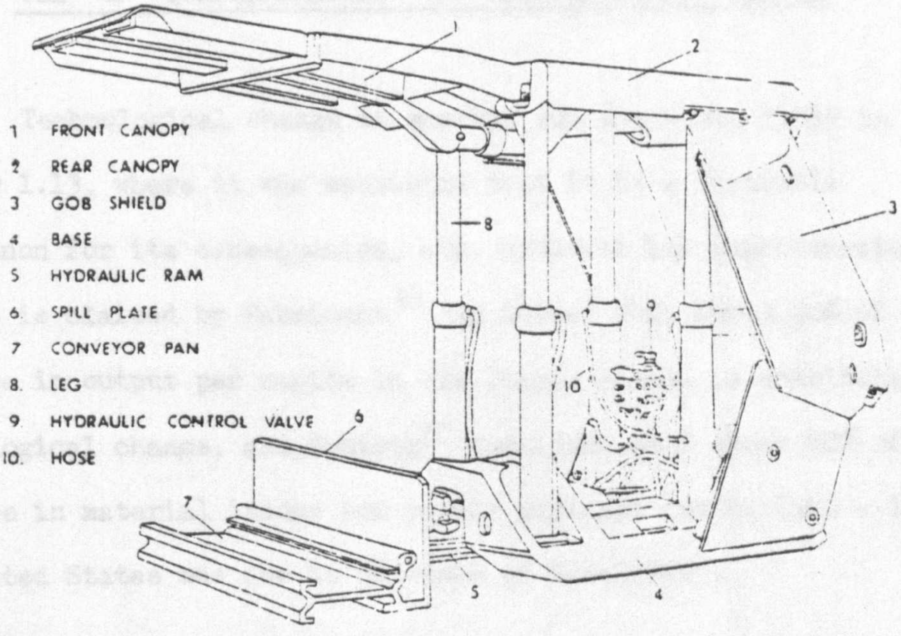


Figure 20: A Chock Shield Support
(from reference number 138)

Powered supports are now firmly established universally, where-ever the longwall method is being practiced. Comparing with other European countries, the speed of adoption has been faster in the U.K. so that in 1976, 96.5% of coal produced in the U.K. was from faces equipped with powered supports. The average for Europe is 87.4%. In France this figure was only 41% and in Belgium 56%[139]. The higher standard of safety at British coal faces as compared with other European countries, can be attributed to the higher number of powered supports in use.

3.4 USE OF QUANTIFICATION OF TECHNOLOGICAL CHANGE

Technological change in general was discussed fully in Chapter 1.13, where it was mentioned that it is a desirable phenomenon for its consequences, e.g. productivity improvements, and that it is claimed by Fabricant[16] and Solow[7] that about 90% of the increase in output per capita in the United States is attributable to technological change, and Denison[17] concludes that about 40% of the increase in material income per person employed during 1929 - 1957 in the United States was due to "Advance of Knowledge".

Technological change measurement would provide the analyst with an indication of the efficiency of the research work associated with particular innovations, provide management with an idea of the effectiveness of past investments and highlight the efficiency of different investment areas, all of which are of great significance in order to ensure efficient technological changes. Further, since technological change is not always the only cause of productivity improvements, the analyst, in his measurement procedure, will inevitably measure the effectiveness of other influencing factors which will also assist management in future planning.

In the present work the rate of technological change has been quantified in the sum of the effects of three variables T, R and $\exp(-\frac{P}{F})$ - see page 201.

4. PRODUCTIVITY IN COAL MINING

The main ideas for this chapter have been dealt with before by Stainer[140]. In Section 2 of his thesis under the heading "productivity and its measurement in underground coal mining" (pp 45-80), he gives a full description of the available literature and explains the shortcomings of the present method of measurement in such detail that little extra material is required in this chapter. The following is therefore only a brief description of the present ideas and methods.

4.1 INTRODUCTION

Productivity has been the primary goal of high level management of the coal industry in the U.K. for the past few decades. Until the late 1960's it was felt that technological developments were causing productivity improvements, but about then technology at the coal face tended to become "conventional" once again and there was little or no improvement in productivity expected from this source. Management, being well aware of the need for greater productivity, established an incentive scheme based on productivity. The basic idea of this scheme is logical, but the criterion by which productivity is judged is examined here.

4.2 O.M.S.

The only measure of productivity actually used in the coal industry, perhaps since mining began, has been the ratio of output to the number of manshifts required to produce it. The only improvements in the measure have been trivial, for example, by changing the unit of output from cwt to tonnes.

OMS is thought to be the measure of labour productivity, that is, how hard people work, although it is misleading to assume that it is possible to separate labour from other inputs. OMS for the coal faces of the U.K. increased from 2.97 to 8.53 from 1947 to 1978. Would one be correct in concluding that miners worked 2.9 times harder in 1978 than they did in 1947? In American coal mines OMS is substantially higher than in the U.K. Does this mean that American miners work substantially harder than British miners? It is obvious that many other factors, such as technological change, geological conditions and capacity utilization influence OMS greatly.

It can, however, be asserted that OMS is a useful tool for some other purposes, such as for measurement of technological change, but it does not measure productivity.

4.3 PRODUCTIVITY OR PROFITABILITY ?

It was concluded in Chapter 1.23 that an analysis of productivity must be embedded in the cost and profitability structures. It is intended here, to evaluate the profitability of the N.C.B. as a whole and compare its movements with those of the dubious measure of productivity, O.M.S. The important question here is, what is the profitability of the N.C.B. and how can it be determined. Remembering that the N.C.B. does not have a complete monopolistic power, due to the existence of some privately owned coal mines, alternative energy sources such as natural gas, nuclear power, oil etc., and the possibility of coal being imported, and the fact that government grants have been available to the N.C.B. for the provision of exceptional social services, it is not hard to imagine that the market price of coal should, in the long run, be the real value of the product. It has, therefore, been decided here that profitability of the N.C.B. should be calculated by the amount of profit made before interest and after government subsidies.

Profit = Mining Activities Profit + Interest - All Grants
Assets = Fixed Assets + Net Current Assets - Deferred Liabilities

Notes:

(1) Assuming that government grants are paid to adjust for the high value of services provided by the N.C.B. to the workmen, and to the nation as a whole, grants are considered as revenue.

(2) Arguably, deferred liabilities have been deducted from total assets. This is a part of total assets mainly used for activities which are not commercially viable, such as cost of restoration of opencast sites, and therefore do not result in financial returns.

Table 8 shows net profit, total assets and the indexed value of the ratio of these, together with that of the overall OMS. Graphs of Figure 21 show that there is negligible correlation between the last two measures, indicating that OMS is not embedded in the profitability structure.

Year ended March	Profit £M	Total assets £M	Profit / total assets %age	Profit / total assets Index	Overall OMS Index
58	19.6	721.4	2.72	100	100
59	17.6	829.8	2.12	78	104
60	14.9	894.1	1.67	61	109
61	22.3	901.0	2.48	91	113
62	32.9	877.7	3.75	138	118
63	48.7	878.2	5.55	204	127
64	43.7	881.6	4.96	182	134
65	36.1	909.3	3.97	146	139
66	- 4.3	796.0	- 0.54	- 20	144
67	25.2	783.0	3.22	118	146
68	29.0	733.6	3.95	145	156
69	17.4	738.2	2.36	87	170
70	- 4.5	653.0	- 0.69	- 25	173
71	21.9	650.6	3.37	124	176
72	-117.5	551.4	-21.31	- 783	168
73	- 49.3	317.8	-15.51	- 570	183
74	-126.9	367.3	-34.55	-1270	169
75	3.5	489.9	0.71	26	180
76	24.6	723.6	3.40	125	180
77	88.2	987.1	8.94	329	174
78	79.2	1309.7	6.05	222	172
79	93.4	1441.1	6.48	238	176
80	1.4	1814.9	0.10	4	179

Table 8 OMS versus Profitability

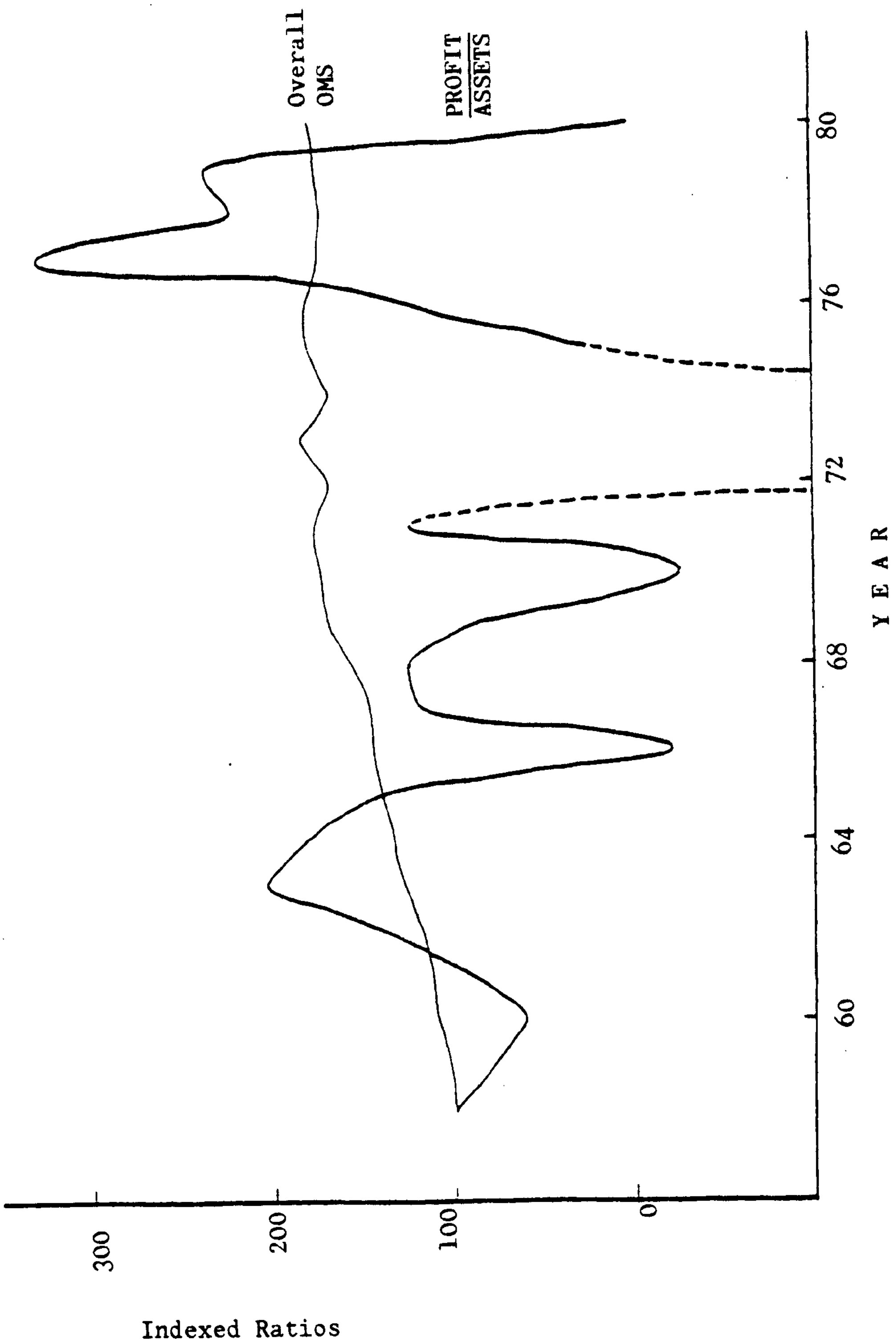


Figure 21 Comparison of OMS and Profitability

4.4 TOTAL PRODUCTIVITY

Enough has been said in the literature in support of the concept of total productivity, that one is convinced easily of its superiority to any other measure. The difficult task is then its application. Stainer[140], the pioneer of this area of study, applied the total productivity concept to the coal mining industries of seven European countries. Although his measurement technique is valuable and by far superior to others, the highest credit should be given to his comparison process. He concludes that total productivity of the U.K. coal mines decreased by 15% despite an increase of 61% in O.M.S. from 1960 to 1976.

In this study, total productivity is adopted as being the most realistic and comprehensive measure, and the exact method of measurement is described in full detail in Chapter 6.

5. SAFETY IN COAL MINING

5.1 INTRODUCTION

Mr Justice Sankey in his first report dated 20 March 1919, used the phrase "stands condemned" to describe safety in mines and Haldane[141] confessed in 1920 that "this is something of which we have good reason to be ashamed".

If the safety is thought of in terms of the number of fatalities, then mining safety would seem to be of greater importance than an average person assumes. Duckhams[142], reviewing the history of pit disasters explains its importance comprehensively. He states: "Ask a man to think of disasters in British history and he will, likely as not, tell you the Glen Coe, the collapse of the Tay Bridge, or the Titanic".

Underground coal mining, being under the ground, has special characteristics, as do working on the sea or in the air, and tends naturally to be dangerous. The dangers associated with coal mining include almost all those of working above ground, plus some risks due to the conditions of working under the ground, such as darkness and space confinement. The risk to the life of coal miners is therefore a good deal greater than in the case of those working in ordinary conditions, and hence makes the study and research of coal mining safety of greater significance. Statistical evidence also proves that both accidents and occupational diseases have always been more frequent in coal mining than in other occupations.

A great amount of effort has been spent in improving safety in coal mines. New methods, new machinery and the imposition of protective regulations are all claimed to have gained this objective, but on the other hand the conditions of working, so far as depth is concerned, have become worse, countering to some extent the effects of technological improvements.

The findings of a piece of research study[124] are interesting, stressing the difficulties with which one would encounter when measuring safety or attempting to assess the effectiveness of a certain safety scheme. This survey concludes that the accident rate amongst divorced or separated men is substantially higher than for others. Also, the more children a miner had, the more accidents he had had. These results, together with others stated in the report, suggest the importance of the psychological state of coal miners in the occurrence of accidents. This is obviously to a great extent outside management control. The coal miners themselves also agreed with this fact. 62% of those interviewed thought this was the main factor contributing to accidents.

Robaye, Hubert, and Decroly[143] showed that men with greater mental stress were more succeptible to accidents than others. The results of Koehegyi and Bedi[144] were somewhat similar.

Considering other causes such as geological difficulties, poor organization, etc., it would seem that only a small number of accidents occur due to the deficiencies associated with technology, implying that technological change has had a significant influence on safety until the present time. In the aforementioned survey[124] it is shown that only about 5.6% of accidents were due to poor equipment or lack of equipment.

This view was also shared by an N.C.B. safety official (Western area chief safety engineer). He suggested (in a private conversation on October 31, 1980) that regarding safety, technology has advanced more rapidly than the men could cope with it, and the most important task is now to induce them to make the best use of these improvements.

It is now appropriate to examine here the current safety situation in coal mines and also the progress made since nationalisation. Fortunately the mining industry for over a century has produced fairly comprehensive statistics of accidents. Table 9 gives the accident rates per 100,000 manshifts worked at each five year point since 1940 in respect of main categories.

Unfortunately the N.C.B. have not classified accidents in accordance with the place of work, such as the coal face, but it can be claimed that the category "falls of ground" relates directly to the coal face accidents.

It should be noted that the rate of accidents shown is related to the total number of manshifts worked underground, and that if data were available for the number of accidents per number of manshifts worked at the coal face, these would be considerably higher. It is frightening to imagine how dangerous it was in 1940 to work at the coal face. This will not seem to be true if one remembers that the number of men at the coal face has gradually decreased while that of other places underground has not (relatively). A statistic would be more meaningful if it showed the rate of accidents per number of manshifts worked at particular places.

Year	Falls of Ground	Haulage and Transport	Explosions, Fires, etc.	Shafts	Others	Total U/ground	Surface	Total U/ground and Surface
			D E A T H R A T E S					
1940	0.33	0.12	0.03	0.01	0.04	0.53	0.16	0.43
1945	0.23	0.09	0.02	0.01	0.03	0.38	0.09	0.30
1950	0.14	0.07	0.08	0.01	0.04	0.34	0.10	0.27
1955	0.13	0.09	0.01	0.01	0.03	0.27	0.14	0.24
1960	0.12	0.06	0.05	0.01	0.03	0.27	0.09	0.23
1965	0.10	0.05	0.04	0.01	0.04	0.25	0.08	0.20
1970	0.06	0.09	-	-	0.02	0.17	0.05	0.14
1975	0.02	0.05	0.01	0.01	0.04	0.13	0.07	0.12
			S E R I O U S I N J U R Y R A T E S					
1940	0.95	0.53	0.04	0.02	0.30	1.84	0.65	1.52
1945	0.77	0.43	0.04	0.03	0.35	1.62	0.43	1.30
1950	0.55	0.40	0.03	0.02	0.39	1.39	0.42	1.13
1955	0.50	0.32	0.03	0.02	0.39	1.26	0.44	1.06
1960	0.61	0.41	0.01	0.02	0.27	1.32	0.57	1.14
1965	0.52	0.44	0.01	0.02	0.33	1.32	0.47	1.11
1970	0.36	0.46	-	0.01	0.37	1.20	0.46	1.00
1975	0.34	0.49	-	0.02	0.45	1.30	0.62	1.08
			D E A T H A N D I N J U R Y R A T E S (Over Three Days)					
1940	33.66	22.00	0.09	0.18	28.93	84.86	26.52	69.48
1945	43.03	30.55	0.08	0.19	49.78	123.63	37.22	100.47
1950	46.78	33.72		84.09		164.59	52.08	134.42
1955	39.31	22.67		84.49		146.47	47.81	122.34
1960	41.73	22.03		104.00		167.76	53.92	140.59
1965	51.09	24.86		163.28		239.23	76.49	198.88
1970	33.20	14.26		126.68		174.14	54.02	141.94
1975	19.15	8.33		92.81		120.28	38.43	99.44

Table 9 - Death and Injury rates per 100,000 manshifts worked at Coal Mines

(From N.C.B. Statistics)

The table, nevertheless, shows that some improvements have taken place to render mines safer, but there can be no complacency where 486 people were killed or seriously injured in 1980[135]. The pace of safety improvements must therefore not slow down, so that further reductions in the number of accidents are gained. Legislation has helped in the past to increase safety, but the main disadvantage with this is that it tends to decrease productivity. On the other hand, the law can be said to have played its part so far, and there is little space for it to expand further at present. If it does, it is probable that it will reduce risk rather than the number of accidents. Technology also has improved vastly tending to make the coal face safer. It is widely accepted now that improvements in safety results have not been as fast as that made possible by law and technology. The blame is therefore put upon the individual workers and the fact that, since 1974 the responsibility for one's safety is put on the miner himself shows this. Since 1970 relatively little technological advance has taken place at the coal face and the officials have only attempted to improve safety by programs such as safety propoganda etc. These have shown only a slight, if any, improvement and the rate of accidents reduction has decreased.

Most of the research work being carried out today regarding coal face safety, is concentrated on pwoered supports and coal face environmental control such as dust, heat and humidity. These areas of research, if they have not already reached full potential, will soon do so, and the situation of 1940's and early 1950's will occur, and indeed to some extent has already occurred. Coal faces are once again equipped with "conventional" machineries (although these are different from those used in 1940's and 1950's) and almost all the work carried out in the past ten years or so has been concentrated on mere modification and development of these conventional systems. A revolutionary idea and action seems to be required to improve safety any further and by a worthwhile amount. Automation of the coal face seems to be the answer. Safety officials of the N.C.B. are particularly in favour of this and they would like to see nobody working at the coal face, since with no man working on the coal face, there could be no accident there.

The six major elements contributing to healthier and safer coal mines have been identified by Collinson[145] as to be: legislation, research, training, campaigning, technology and organized safety efforts. From the list, two, namely research and technology, relate directly to technological development. It is expected to find that technological change has been the main cause for improved safety. Mining engineers together with safety officials of the N.C.B. believe that about 80% of the improvements in safety have been brought about by technology. However, for technology to be developed along a desired line, research is required.

It would perhaps be of some interest to show the degree of danger present in coal mines, comparing with other industries by statistics. Table 10 gives a comparison, placing mining in the context of some heavy industries.

Industry	Fatal accidents frequency rate (per 10^8 hours)
Shipbuilding	7
Construction	10
U.K. Manufacturing Industry	2
U.K. Coal Mining (overall)	16

Accidents in Heavy Industries

Table 10: Source: H.M. Inspectorate of Factories 1972-73 and N.C.B. Statistics

It is evident from the Table that mining remains about twice as dangerous as other heavy industries in the U.K. If, however, a comparison is made between safety in the U.K. coal mining industry and that of other European countries, it will be shown that Britain has about half the European rate of accidents both in terms of hours worked and tonnage mined.

Period	Rate per 10^8 hours worked U/G				Rate per 10^8 tons mined		
	U.K.	Germany	France	U.S.A.	U.K.	E.C.S.C.	U.S.A.
1960-64	32	78	36	106	119	236	54
1965-69	27	56	40	103	80	153	44
1970-74	20	41	50	88	50	104	38

Mining Accidents in Different Countries

Table 11: Reproduced from the symposium of Health, Safety and Progress, Harrogate 1976

5.2 HISTORICAL REVIEW OF SAFETY IN COAL MINING

In the early days of mining (thirteenth, fourteenth and fifteenth century), the major cause of accidents, was falls of ground. Gas and water were added in larger measures in the sixteenth, seventeenth, and the first half of the eighteenth century. The first stage of technological development, that of steam engines eased the problems caused by the existence of water in mines which in turn resulted in drier conditions of working. As a result the problems of gas and dust were accentuated, due on the one hand to drier conditions, and on the other hand to inadequate ventilation arrangements, which brought about the great hazard of explosions. Although statistics were not compiled before 1850, it seems likely that during the first half of the nineteenth century deaths resulting from explosions exceeded those from falls of ground. Also at about this time accidents frequently occurred in shafts, and according to Hudson[146] in the period of 1851 - 1853, the annual number of deaths from explosions, falls of ground and shafts were 267, 348 and 221 respectively.

Further technological change took place leading to the provision of safety lamps, and more efficient and regular ventilation systems. As a result of these developments, although the number of disastrous occurrences was reduced, their magnitude increased with the size of the mines, resulting in no improvement overall from the safety point of view - the greatest mining disaster of British mining happened in 1913 when 439 lives were lost. Table 12 illustrates these facts statistically.

Period	Number of Explosions	Number of Explosions Per Year	Number of Persons Killed	Number of Persons Killed Per Year
1835-1850	643	40.2	NOT RECORDED	
1851-1900	2,223	44.5	10,079	202
1901-1920	317	15.8	2,301	115
1921-1935	188	12.5	985	66
1936-1953	139	7.7	856	48

Fatalities due to Explosions 1835-1953

Table 12: Reproduced from reference number 146

In the period from 1920 to 1950, these major causes of accidents were eliminated to a large extent, mainly through the influence of legislation and technological developments. By this time, although the number of accidents due to falls of ground had reduced considerably, it was still, together with haulage, a major cause of accidents underground, so that for example in 1954 these two were the cause of about half of the fatalities underground in Britain.

Table 13 gives in full the available statistics for safety since 1850.

After nationalisation the trend for both the number and the rate (number per 100,000 manshifts worked) of accidents show a decline, but the more important one, the latter, shows a slower improvement. In the late 1960's, and particularly during the 1970's, the trends are almost horizontal lines, and recent statistics show only fluctuations without a marked trend.

One of the major objectives of nationalisation of the coal industry was to improve safety and it is left to individuals here to assess the Board's success.

Table 13 : Average Number of Persons Killed and Injured per Year

Years	Manpower	Explosions	Falls	Shafts	Haulage	Other U/G	Surface	Total
			KILLED					
1851-53	174,000	267	348	221			45	975
1874-76	420,952	183	440	152	126	71	106	1,078
1898-1900	591,452	42	454	71	170	90	119	946
1924 & 25	934,979	32	577	46	261	141	111	1,168
1949-51	545,766	36	198	15	92	77	42	460
1953	553,069	4	174	22	91	26	47	364
			REPORTABLY INJURED					
1898-1900		207	1,718	131	933	725	494	4,208
1924 & 25		133	1,772	96	1,219	809	543	4,572
1949-51		34	759	17	472	550	218	2,050
1953		28	716	11	445	513	194	1,907
			ALL INJURED (COMPENSABLE)					
Over 7 days 1911	863,512	185	58,522	633	44,275	50,660	12,341	166,616
Over 7 days 1923	979,785	101	70,007	932	54,360	68,967	17,889	212,256
Over 3 days 1924 & 1925		116	62,789	1,138	46,351	60,670	15,677	186,741
Over 3 days 1947	551,841	73	51,179	256	33,483	61,085	16,468	162,544
Over 3 days 1949-1951		103	61,771	103	39,929	109,366	23,512	234,784
Over 3 days 1953		51	58,308	131	35,537	116,081	22,244	232,352

Note 1: Numbers for the years up to and including 1947 are taken from the Inspectors' returns.

Note 2: Numbers for the years 1949 and later are taken from the N.C.B. returns.

In the 1960's with the introduction of powered supports, one of the important problems causing fatalities due to falls of ground, was eased, and if the total number of accidents from this source is considered, then a good improvement will be noticed, but if the rate of accidents is thought of, then the improvement will not be as great due to the reduced number of men working at the coal face. This implies that the risk to the life of individual miners was not reduced markedly.

Falls of ground is still nevertheless one of the major sources of accidents, but it has been exceeded by haulage and transport, and still these two are the cause of more than half of all fatalities and injuries underground.

Figure 22 shows the number and rate of accidents since nationalisation.

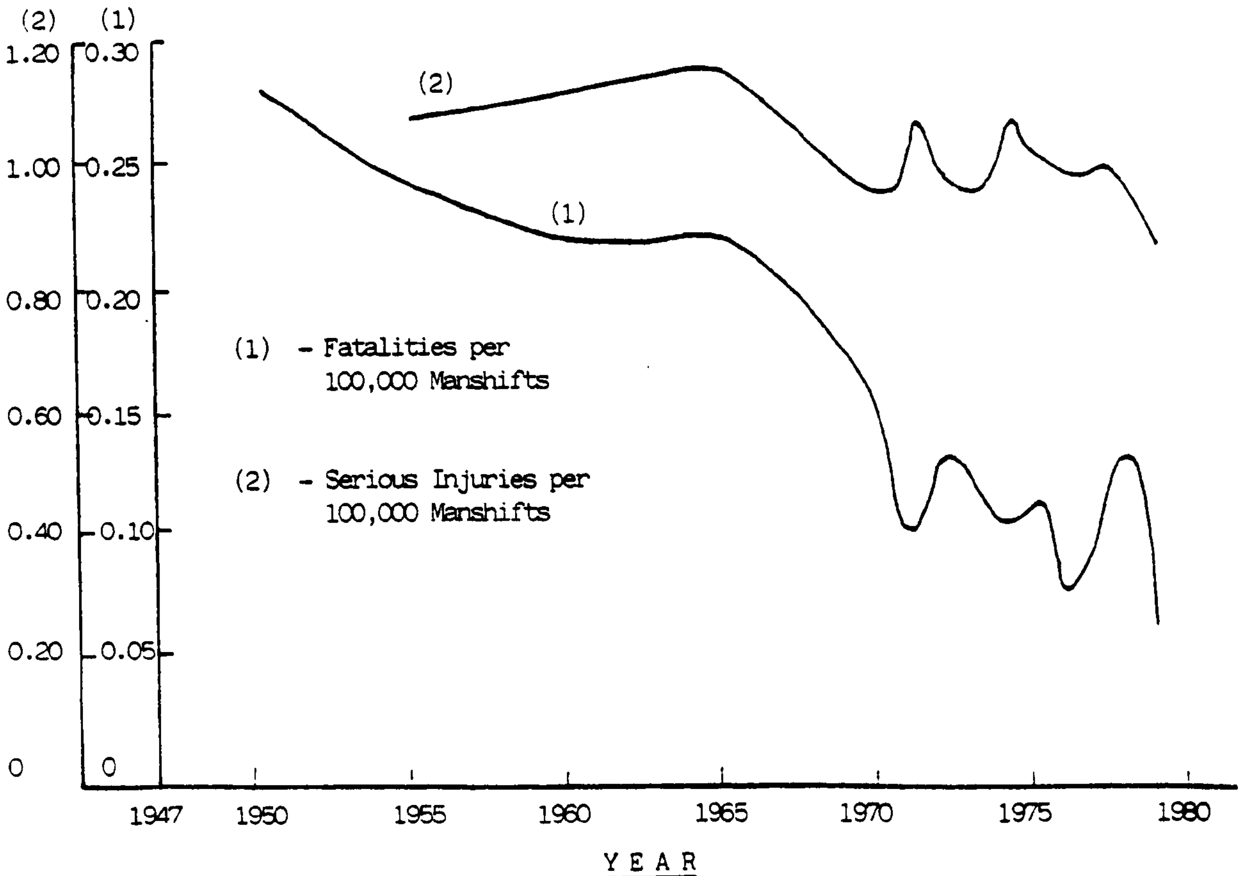


Figure 22: Safety Since Nationalization
Source: Health and Safety Executive Reports - Mines and Quarries

5.3 HEALTH OF COAL MINERS

Mining engineering has been said to be the art of providing an environment underground in which men can work with safety and without damage to their health. Although some of the health hazards of mining, notably those affecting the lungs, have been known since mining began, it was naturally to accidents that mining engineers first turned their attention. On the health side it is only within the last fifty years or so that scientists and physicians began to have the expertise to identify with accuracy those diseases that arise from the mining environment, and to be able to suggest means of controlling them.

The importance of health in mines, compared with that of safety, is realised when mentioning some figures. Many coal miners suffer from simple pneumoconiosis which, without pulmonary disease, causes little disability and has no effect on expectation of life. But men with simple pneumonocomiosis have a substantial risk of developing Progressive Massive Fibrosis, which causes distinct disability and reduces life expectancy. About 1500 miners now working in mines have Progressive Massive Fibrosis[147]. Also, roughly half of the 39,000 men who are at present (1976) alive and compensated for pneumoconiosis will develop Progressive Massive Fibrosis before they die, and many of these will die from it[147].

In contradistinction to accidental imjuries, diseases of mining generally have a long time span between the first causal stimulus and the development of a recognizable disease. Often causation does not arise from a single factor, but from several, inside and outside the working environment; and, particularly, in respiratory disease the effects can be complicated by non-mining diseases (as expressed by A. Azadmand, a specialist in chest radiography). It is, therefore, not surprising that a detailed study of the health problems of miners was rather later on the scene than that of safety.

Until the last two or three decades medical effort was mainly spent on the identification of mining diseases. Certainly the respiratory risk in mining had long been recognized, but the medical equipment available was limited, and it was in the early 20th century that X-ray examination in particular began to allow accurate diagnosis of chest disease during life.

Improvements from the health point of view have taken place and once again, technological change has played a major role. Improvements in illumination have eliminated diseases related to the vision of miners. Mechanised transport has caused the disappearance of ponies, which, coupled with rat control, has caused the disappearance of rat-borne disease; and great improvements in ventilation have done much to reduce dust exposure and its effects. Dust, however, still remains the major hazard to the health of coal miners, and is the subject of much research at present.

5.31 Pneumoconiosis

The term pneumoconiosis literally means "dust in lung": a general term applied to all those diseases caused by inhalation of "any kind of dust". The expression "any kind" originates from the report produced by a group of researchers from the Industrial Pulmonary Disease Committee of the Medical Research Council, which began in 1936[148]. Prior to this report, it was thought that coal dust was harmless, and that only rock dust produced lung diseases. For example, in 1927 Haldane[149] expressed his view as: "The inhalation of coal dust causes no danger to life, but on the contrary gives even protection against the development of tuberculosis."

Most of the dust inhaled is either exhaled or otherwise eliminated by the same breath or in the next 24 - 48 hours. Some of the small particles are however deposited in the terminal air passages from where they are carried into the lung tissues and if a sufficient amount of these are retained, then eventually pneumoconiosis will be produced, which causes partial or total disability and finally death.

McLintock[147] claims that there have been marked improvements in the industry regarding pneumoconiosis, but since inevitably a relatively long period must elapse between such remedial actions as regular medical examination and dust control, and the beneficial result, there is not enough statistical evidence to prove this. However a slight improvement is shown by the few statistics available.

Table 14 shows the number of new cases of pneumoconiosis diagnosed by the medical panel of the Department of Health and Social Security from 1945 to 1975.

Year	No. of diagnoses
1945	5,821
1950	4,376
1955	4,997
1960	3,279
1965	1,007
1970	773
1971	623
1972	626
1973	515
1974	539
1975	683

Number of Pneumoconiosis cases 1945-1975

Table 14 - Reproduced from reference number 150

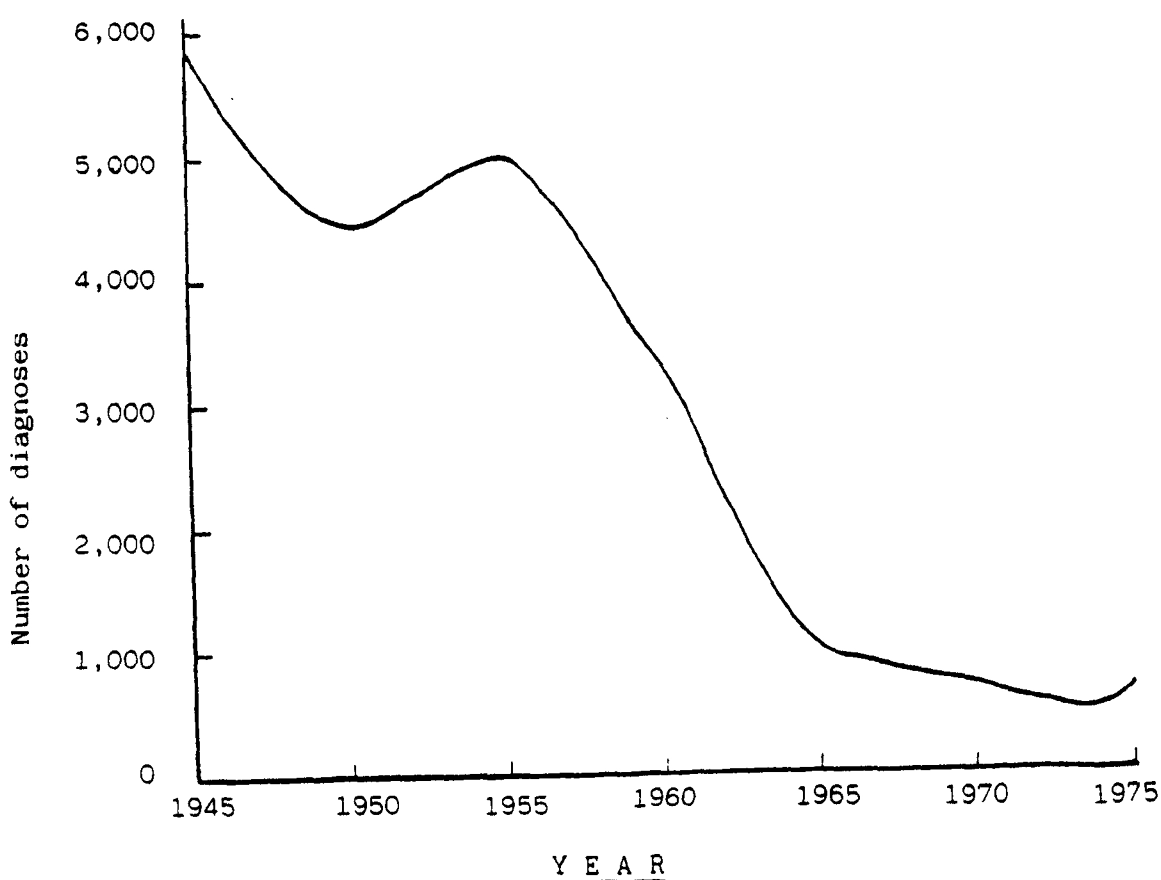


Figure 23 Number of Pneumoconiosis Cases

Since the disease was recognized (just before the period in question), there was a steady reduction in certifications, but there has been no significant change recently. A great deal of effort has been spent oncontrolling the dust level, to examine miners medically on a regular basis, etc., but the end result is not satisfactory and in this respect too, a major technological change seems to be called for.

Interest has been shown in pneumoconiosis by people and institutions other than those related to mining. Notably, the publication of "The Medical Press" can be mentioned, which in its early years, by the articles of McLintock[151], Meiklejohn[152], Doig[153] and some others, explained the nature of the disease, its diagnosis and medical means for its prevention.

5.32 Other Diseases

Other diseases associated with coal mining, which to a large extent have been minimised are: beat diseases, dermatitis, miners' nystagmus, Weil's disease, epidermophytosis[154]. Treatments are relatively simple although in the case of Dermatitis to which there is a psychological element attached, it becomes more complicated[155, 156].

5.4 COSTS ASSOCIATED WITH HEALTH AND SAFETY

Much has been written about effects, both social and economic, of lack of safety. Tregelles & Hartley[157] stated that, occurrance of accidents is unacceptable both from social and humanitarian point of view and their effect on productivity. Duckhams[142] by examining the past statistics gives a full account of these social effects. As a result of various Acts, imposed to protect the health of miners, those suffering from pneumoconiosis were compensated and forced to leave the industry (as "certified men"). It was concluded by social surveys carried out that in many cases certification produced considerable mental depression. Many men said that they had not wanted to leave the mines; that their accustomed way of life had been broken up; and that they feared the loss of income and insecurity of their future[158]. The National Joint Pneumoconiosis Committee's working party[159] gave similar conclusions.

In the above survey[158], it is claimed that many of the certified men were severely frightened by their diagnosis. Almost all had seen friends or relatives die of the disease and naturally they tended to assume that the same fate awaited them. These fears would obviously further increase disabilities.

From the economics point of view it can be mentioned that, between 1940 and 1947, as many as 18,000 skilled men were certified[158] and hence left the industry, which should certainly be considered as a waste of economic resources of the community as a whole.

Between 1944 and 1946, about £3 million was paid as compensation to coal miners of South Wales[158]. The cost of providing compensation in 1945 and 1946 for South Wales coal miners only, was £5.5 million, equivalent to 3s per ton of coal produced.

In 1975, the total number of shifts lost due to accidents was 1,170,862. This with an O.M.S. of 44.8 cwt and the price of coal at £18 per ton, would give a loss of £46.366 million[160].

Christenson & Andrews[161, 162], have well noted the great current interest in, and concern with achieving, improvement of safety and health in the coal mines' labour force, both from the economic and social points of view.

It is undeniable that accidents cost money, and although some figures have been produced above, they are by no means indicative of the real cost of accidents. It is extremely difficult to give reliable estimates of the cost of accidents, but some attempts have been made to do this.

Collinson[163], for example, has attempted to give a comprehensive list of all different types of costs associated with accidents, so that he could give an estimate of the financial cost of accidents, but he did not even mention the social costs. He finally arrived at the figure of £50 million to be the cost of accidents per year (1979 prices). On the other hand, this type of calculation measures the cost only from the N.C.B.'s point of view, and any cost to others such as the public is ignored.

Collinson further tries to measure the cost effectiveness of further accident prevention effort and he concludes that investment on safety would still give a good rate of return. Obviously such a conclusion cannot be expected to be of any degree of reliability, until a comprehensive cost-benefit analysis, considering all social and economic factors, is carried out.

5.5 EVOLUTION OF IMPROVEMENTS IN HEALTH AND SAFETY IN COAL MINES

Varying efforts and divers techniques have been employed in different industries to improve health and safety. In the mining industry the effort has been intense. Early interest in the improvement of working conditions manifested itself in the pressure from the work-force for legislation, backed by social pressure, and there was perhaps the inevitable resistance to the regulatory approach by the influential coal owners and landlords who foresaw heavy expenditure being incurred in creating safer and healthier operations[164]. There was little realization that safety improvements had literally to be purchased.

Early legislation was more concerned with social matters, such as hours of work and child employment; but it was a start, and ultimately the first mines' inspectors were appointed in 1850 and there began a period of increasing legislation and increasingly relevant and specific mining law.

Much of the early safety effort was based on past experience, and to a large extent this remedial effort has continued, bitter experience usually generating remedies through sponsored research, or calling for the application of known remedies.

Hitherto, then, much effort was ad hoc: an accident, which was not always unforeseeable, occurred; investigation followed, and remedies were either suggested or required statutorily. Reid[165] in his paper in 1938 states that: There was some professional effort prior to nationalization by a few enlightened colliery companies, and safety specialists appeared in management structures in the 1930's, when a few intensive campaigning operations were commenced.

After this period, considerable change was encountered - nationalization in 1947. The opportunity was taken to consider health and safety as an entity, and to begin the management of it. Increased effort could be mounted; resources could be made available through Board decisions; there was at last the opportunity for country-wide application of safety expertise, and training for safety could be firmly and professionally based. Large scale campaigning could be initiated, and 1962 became the first national safety year.

It is claimed by Collinson[166] that since about 1965, determined effort no longer lagged behind legislation, and the attack on air borne dust arose through the industry's resolve: the recent legislation was only the seal.

Collinson[145], somewhere else, looking ahead of the present time, by giving interesting examples states that if the hazardous nature of a cause of accidents is removed, then automatically the risk is eliminated. He exemplifies this with reference to the accidents due to chain breakage on the face, and now that chainless haulage has been introduced, the hazard has vanished. He fails to mention however that new systems are bound to introduce new hazards.

These explanations by Collinson are given mainly as justification for his famous idea of "Zero Accidents Potential". Theoretically, zero accidents means zero cause, and since Collinson[167] himself has stated somewhere else that workers themselves contribute to the existence of hazard, would this not imply that zero accidents means no person working? He could mean total automation. But although automation means removing the men, and therefore no accidents, it would not automatically result in any increase in productivity (and indeed if total productivity is considered then a reduction is almost certain) and for this reason efforts should preferably be spent only on removing the hazard present.

It has already been mentioned that one of the main causes of accidents is the falls of ground, relating directly to the coal face. Although this was realized in the 1950's and powered supports were developed in 1960's still, as commented by the Health and Safety Executive[168] in 1978, the 26 accidents in the prop-free-front area of power loaded faces suggest that the desired objective of a man-free-front area is far from being realized.

Regarding face safety, the picture of the European countries is somewhat similar. In West Germany about half of the total accidents occurred at the face. This proportion is similar for France and Belgium and in the case of the rest, it is about one third [169].

Figure 24 shows that, although the number of accidents at the coal face has decreased, this has been due mainly to the reduction in the number of men working at the face, so that the rates do not show such an impressive improvement as the absolute numbers.

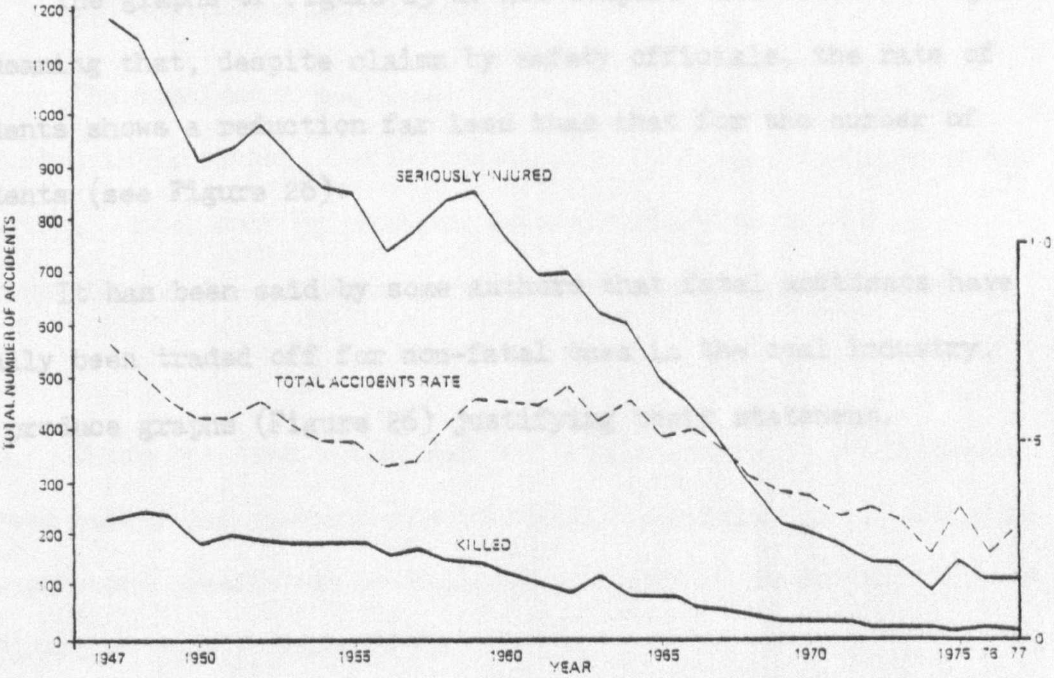


Figure 24: Falls of Ground - Total Accidents
From Health and Safety Executive Report 1977

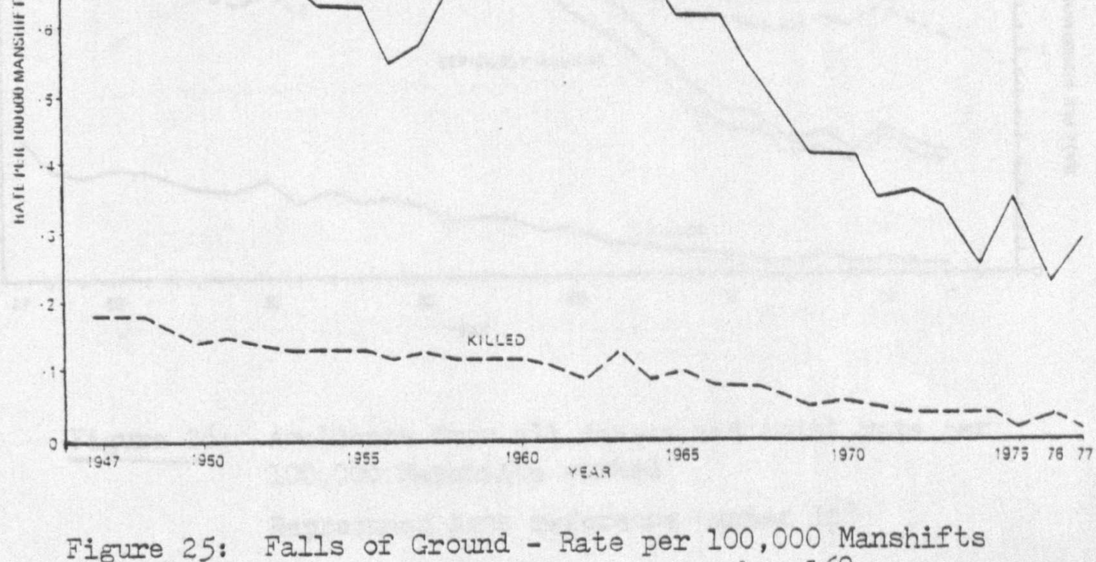


Figure 25: Falls of Ground - Rate per 100,000 Manshifts
Reproduced from reference number 168

The graphs of Figure 25 do not compare with those of Figure 24, meaning that, despite claims by safety officials, the rate of accidents shows a reduction far less than that for the number of accidents (see Figure 26).

It has been said by some authors that fatal accidents have actually been traded off for non-fatal ones in the coal industry. They produce graphs (Figure 26) justifying their statement.

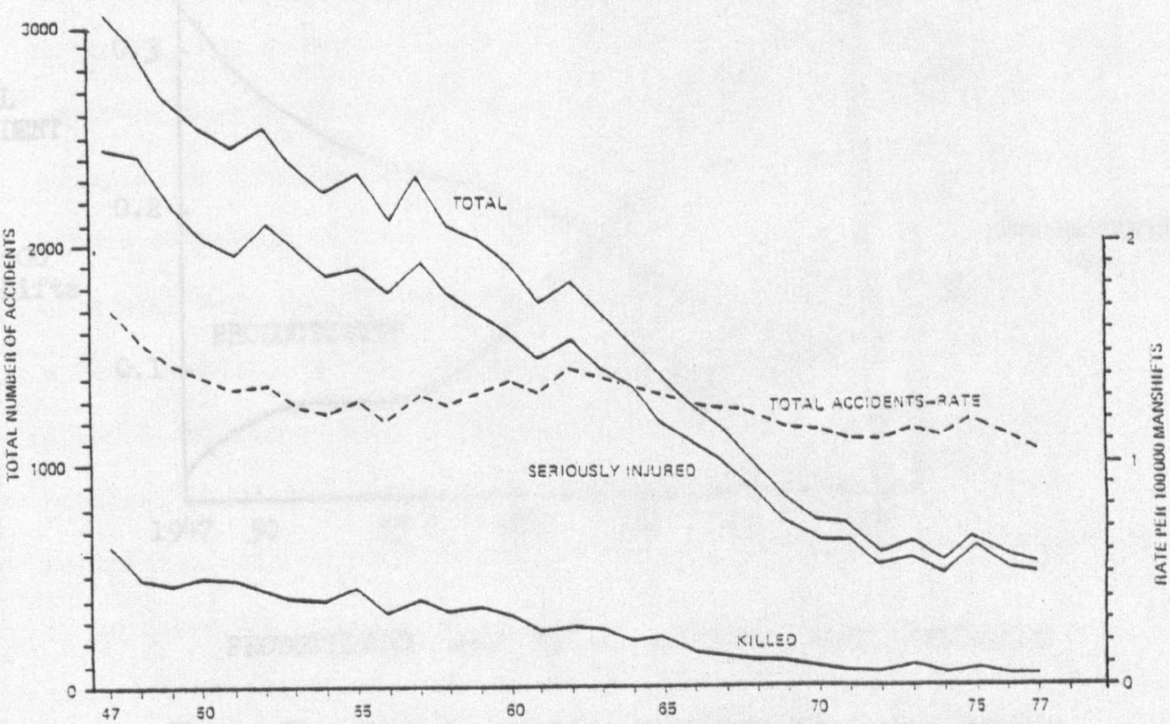


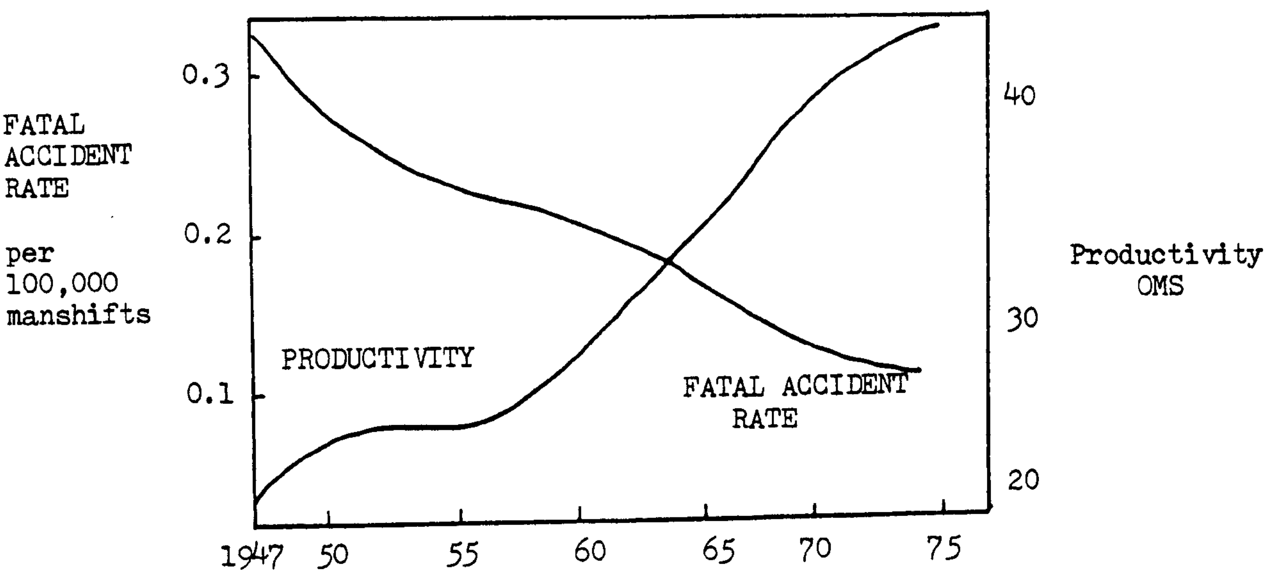
Figure 26: Accidents from all causes and total rate per 100,000 Manshifts worked

Reproduced from reference number 168

5.6 SAFETY VERSUS PRODUCTIVITY

The management and study of health and safety cannot be conducted in isolation, for it constitutes only one objective of the industry. Coal must be produced more efficiently, and it is appropriate and desirable to achieve these with a higher degree of safety.

There has been widespread discussion about the relationship between safety and productivity. Statistical evidence is such that contradictory results can be deduced. Figure 27 shows productivity (OMS) versus safety since 1947.



PRODUCTIVITY AND FATAL ACCIDENT RATE 1947-1975

Figure 27: Source: Health and Safety Executive Reports and N.C.B. reports and accounts

Collinson[145, 171], for example, draws the conclusion that "a safe pit is a productive pit" without any reliable justification. Other authors, particularly non-mining engineers, have concluded that safety and productivity move in opposite directions. Evans[172], by three examples, namely dust control, design of powered support, and chain haulage tries to justify his thesis which is "the efficient machine is also the safe one". Wood[173] also by relatively little statistics claims that safety and productivity move in the same direction but fails to examine the case in depth. He takes fifteen mines to be representative of all mines, and a major fault should have been seen to have arisen from this procedure.

To find out which of these contradictory results is more reliable, the factors which cause safety must be examined. If improved safety is brought about by a piece of legislation, for example, or colliery manager's safety instructions, productivity can almost certainly be expected to decrease. When for instance, part of a coal seam is left to provide better roof conditions merely for safety reasons, or the cutter/loader attendant is by instructions prohibited from moving freely along the face so as to maintain continuity of production, or the manpower transport speed is restricted, and so many others, how can one expect higher productivity to be achieved directly as a result of the enforcement of these restrictive practices, and indeed the opposite is more likely to happen? The only argument against this is that in the long run, owing to the safer conditions that the practices produce, morale tends to increase and simultaneously productivity. This idea is subjective, and may be true in some cases. The view was shared by

Tregelles[174] when he implied that the main reason that productivity did not increase substantially for eighty years prior to 1960, despite technological developments, was that increasingly severe constraints were imposed by law.

Also relevent and more surprising is that Christenson & Andrews[133], by the help of mathematical models and actual data from the U.S.A., prove that the legislation imposed has been associated with unchanged or possibly even higher injury rates. They imply that legislation reduces safety, as well as productivity.

If, on the other hand, as is the case most of the time, improved safety has been the result of technological development and specially after nationalization, machines have been designed with a view to increasing productivity and safety, then it can be expected that these parameters will move in the same direction.

Furthermore, if Collinson had used the graph of total number of accidents versus productivity, or alternatively any rate of accidents versus total, as opposed to partial (labour), productivity, he could not have deduced what he intended to.

It has been suggested somewhere else by Collinson[166] that although productivity does not automatically result in safety, the opposite is true i.e. designing equipment with a view to safety raises productivity. This may be the case when considering only a partial measure of productivity, but would it still stand if total productivity i.e. the ratio of output per input, which is indeed a more realistic one, is considered? Take for instance a coal face fully equipped with automatic devices and no man is needed at the face. In such a case the rate of accidents would approach zero, and productivity (as defined by Collinson) would approach infinity. When considering real productivity and taking into account the capital investment involved, would productivity still look so impressively improved?

Tregelles[174] examined the statistics and showed that the opposite to Collinson's[166] conclusion is true, that is, safety improvements do not necessarily result in increasing productivity, while improvements in productivity may well bring about a higher safety.

Having discussed the matter of safety and productivity with some mining engineers specialized in safety, I concluded that a phrase "productive pit is a safe pit" is more reliable than the reverse. The reason for this is apparently that highly productive mines are usually those with good geological conditions allowing better equipment to be installed and better methods to be practiced, which in turn means the achievement of a higher safety record. These two seem to be compatible, but there is no inherent correlation between them.

6. NEW METHODOLOGY FOR QUANTIFYING PRODUCTIVITY IN COAL MINING

6.1 INTRODUCTION

It has been concluded with sufficient justification, in earlier chapters, that the present measure of productivity in the coal industry, viz output per manshift (OMS), being a purely physical measure, is of little value as a productivity measurement.

Many different methods currently used, most of them purely financial measures, were described in Chapter 1.23. A serious shortcoming of financial measures is that they tend to measure profitability only, and also they may lack practicability. Physical measures on the other hand, tend to measure efficiency; although in the short run, and with some qualifications, they may well measure productivity.

It is concluded here that a realistic and practical measure of productivity is most likely to be an empirical one, based on physical/financial data.

6.2 TECHNICAL PRODUCTIVITY

This could be called "efficiency" of production or even "capacity utilization", a purely physical measure. It can be argued to be a measure of efficiency rather than productivity, and can, in principle, be measured with respect to any one of the input components, eg. labour or capital. This measure of labour productivity would be particularly difficult to calculate. As in the case of OMS, it would ignore all inputs except labour. It would have little value as a measure of productivity. On the other hand, technical productivity, where capital is the only input considered, is more easily calculated and of some interest, although it is deficient in other respects as a measure of productivity.

Similar measures to this have already been used as indicative of productivity. Rice[86], for example, takes the ratio of actual output to expected output as a measure of productivity. Technical productivity is simply the ratio of "actual output" to the "potential output" in IDEAL situations.

Coal faces are equipped with different cutting/loading machines. In 1980, 87% of the total output from longwall faces was extracted from faces equipped with shearer-loaders, and hence for simplicity based on uniformity, only these faces are considered. It must be noted that, technical productivity is not claimed to be a good measure of productivity for it measures that of capital only, but it is used here to reveal some facts and also be used in later models and discussions.

6.21 Actual Output

Values for actual output for the years 1958 - 1980 from shearer-loader faces are derived as:

Actual Saleable Output under consideration = Total Deep Mined Output x fraction of Mechanised Output x fraction of Output from Longwall Faces x fraction of Output from Shearer-Loader Faces per Longwall Face

These values are simply derived from N.C.B. publications and adjusted for saleable tonnage and year definition.

To adjust for years 1958-1962, the following method is used:

$$\text{Output for year ended March } x = \tfrac{3}{4}\left[\text{Output for year ended Dec } (x - 1)\right] + \tfrac{1}{4}\,(\text{Output for year ended Dec } x)$$

To adjust for year duration for the values of the other quantities in the above equation, similar methods have been applied.

Values are tabulated in Appendix 6.21(P 217).

6.22 Potential Output

Potential output from longwall faces with shearer-loaders with respect to capital is the tonnage of coal potentially possible to be won by present capital equipment in use.

Potential Output per Year = 31.536 F' B g V w s' v

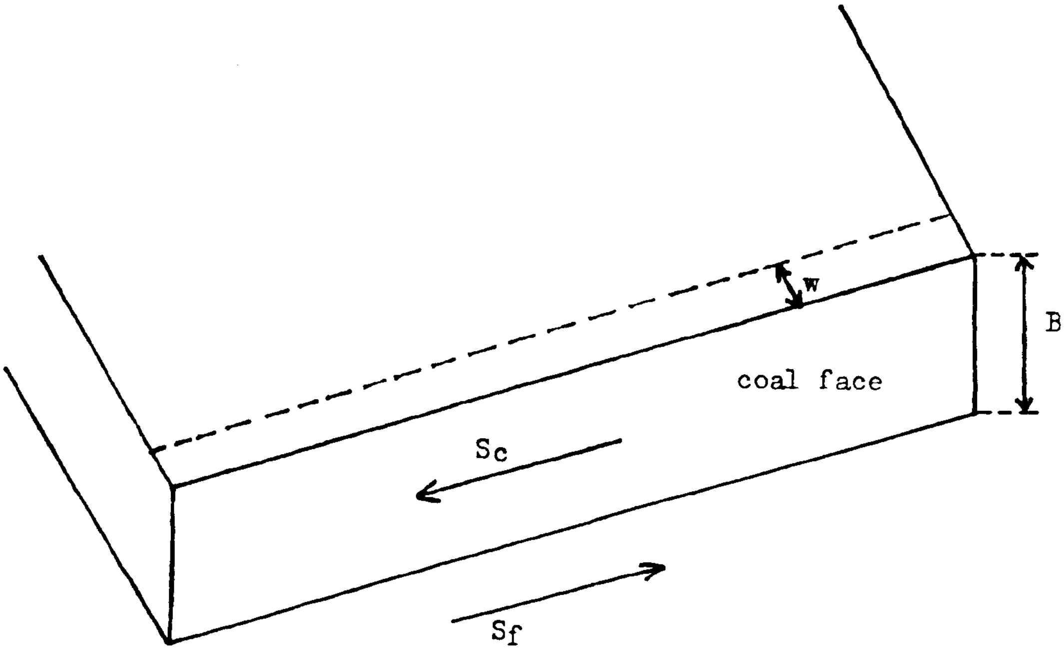


Figure 27a A Simplified Coal Face with Shearer Loader

$\underline{F'}$ is the number of faces equipped with shearer-loader, figures for which are obtained thus:

for some years directly derived from N.C.B. statistics.

for others: F' = F x (fraction of output from shearer-loader faces per unit of output from longwall faces) x 0.981

where F is the total number of longwall faces.

The adjustment factor 0.981 is to allow for the fact that shearer-loader faces are more productive than others. It is derived from figures for those years which are available.

$\underline{B}$, $\underline{g}$, $\underline{V}$ are the mean extracted seam thickness, specific gravity of run of mine coal and vend respectively - all available in N.C.B. publications. Values for B have been adjusted for year.

$\underline{W}$ This is the weighted average <u>economic</u> potential depth of cut (web). The true average may therefore be slightly lower.

Values of web were estimated by personal interviews with those involved in the mining industry and manufacturers, and by using N.C.B. publications, in particular the "Production and Productivity Bulletin".

$\underline{s'}$ is the average number of shearer-loaders on one face. Some faces are equipped with more than one. Simultaneously with the tendency to employ more than one shearer-loader on a face, the innovation of ranging drum and Bi-Di has tended to remove the need, and hence the average number shows a <u>slight</u> increase. Figures for this have been derived from N.C.B. publications.

$\underline{v}$ is the average effective cutting speed of shearer-loaders.

Values have been obtained from various publications of the Institution of Mining Engineers. It must be noted that (P 218) the increase in v over the years, is partly due to elimination of the "flitting back" operation.

Let S_c be cutting speed

S_f be flitting speed

i) When flitting is carried out,

$$v = \frac{S_f \times S_c}{S_f + S_c}$$

ii) When flitting is eliminated, $S_f \longrightarrow \infty$

$$v = S_c$$

Values for the components of potential output are tabulated in Appendix 6.22(p 218).

6.23 Measurement of Technical Productivity

From these appendices, values for technical productivity, as a percentage, are calculated simply as the ratio of actual output to potential output. These values, from which graph of Figure 28 is plotted, are tabulated in Appendix 6.23(p 219). The figures are, perhaps, surprisingly low. This is discussed later (see section 6.333).

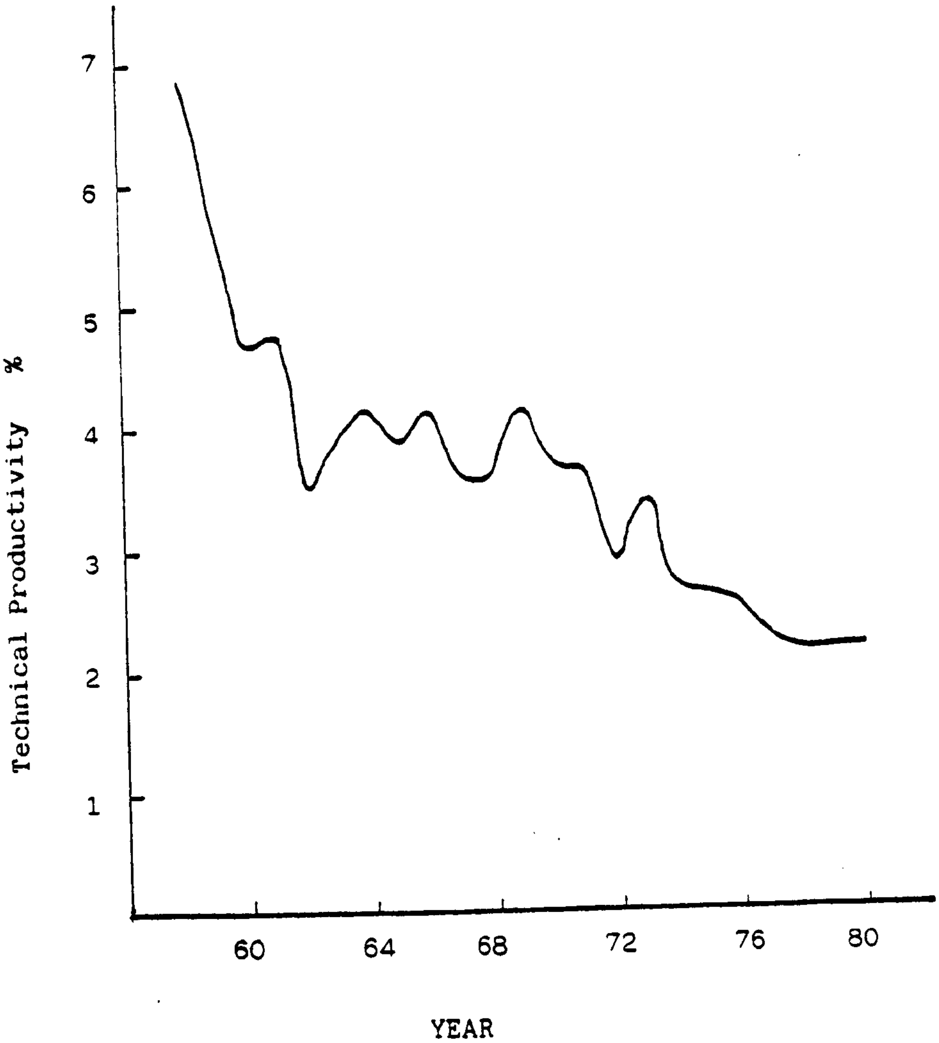


Figure 28 Technical Productivity 1958-1980

6.3 TOTAL PRODUCTIVITY

This is defined in Section 1.25, simply as the ratio of total outputs to total inputs, based on physical/financial parameters. It is adopted here, to measure the "real" productivity of longwall coal faces of the U.K. coal mining industry for the years 1958-1980.

$$\text{Total Productivity} = \frac{\text{Total Output in Tonnes}}{\text{Total Inputs in Pounds Sterling}}$$

6.31 Total Output

This is tne tonnage of saleable coal produced from longwall faces. Allowance has been made for stock variations, and figures include slurry and recovered coal from colliery tips where they were saleable.

It is sometimes argued by economists that the money value of output should be used. Since the interest here is more the technical, engineering and practical points of view, rather that economics and theoretical, using the money value of output which allows for quality would be a departure from the aim of this work. Also, as variations in price due to N.C.B. pricing and marketing policies and the market conditions due to scarcity of substitutes would add considerable irrelevant complications to the study, the tonnage of saleable coal is used as the output. Furthermore, in some areas or mines, the quality of seams being extracted, through no fault or deficiency of management or labour force, is lower than in others and allowing for this, the values obtained for

Productivity would not be realistically indicative of the "real" productivity of labour force, capital equipment, etc.

6.311 The Output Model

It is postulated that, in any year :

$P = f\,(F, T, B, d, s, D)$

and $P \propto (F^{\alpha} . T^{\beta} . B^{\gamma} . s^{\omega} . d^{\sigma}) - D$

$\therefore$ $P = (K\,F^{\alpha} . T^{\beta} . B^{\gamma} . d^{\sigma} . s^{\omega}) - D$

where P is the total output from longwall faces,

F is the number of longwall faces,

B is the mean seam thickness,

d is the mean number of days worked per year per face,

s is the mean number of shifts worked per day per face,

T is the mean tonnage of coal produced per shift per face,

D is the dispute tonnage, and

$K, \alpha, \beta, \gamma, \sigma, \omega$ are constants.

After consultation with experts in coal mining, the following values for the constant and indices were tried, and found to fit the collected data very well.

$K = 0.84 \times 10^{-6}$ $\alpha = 1$

$\beta = 1$ $\gamma = \frac{1}{2}$

$\omega = 1$ $\sigma = 1$

The model thus becomes:

$$\underline{P = (0.84 \times 10^{-6}\; F\; T\; s\; B^{\frac{1}{2}}\; d) - (D)} \quad \text{------------ 1}$$

For full explanation of the modelling procedure see appendix 8.0 (p243).

F & B have been discussed before (See Section 6.22)

T it is essential to take into account the effect of improved equipment on output. Tonnage of coal produced in any shift (T) seems to be a good indicator of this. It incorporates improvements in all areas of coal faces, i.e. cutter/loader, supports and other ancillary equipment. T also has another role here which is to allow for changes in machine running time. In brief, T is to allow for everything but F, B, s and d, that is the residual.

Values for this, although readily available in N.C.B. publications, have been adjusted for saleable tonnage, year and major longwall faces.

Adjustment for years 1958 - 1980:

For year ended March t, $T = \frac{3}{4}\left[\text{value in Sep. } (t-1)\right] + \frac{1}{4}\left[(\text{value in Sep. } t)\right]$

Adjustment for saleable tonnage:

Saleable T = Pithead T x Vend = $T_p \times V$

S & D are average number of shifts worked per day and the tonnage of coal lost due to disputes etc. respectively. Available in N.C.B. statistics - adjusted for years.

d is the mean number of days worked per year per face, values for which are derived as follows:-

$$d = \frac{\text{Total output per year}}{\text{output per day x number of faces}} = \frac{P + D}{\text{Output per day x F}}$$

Values for F, T, d, S, B and D are tabulated in Appendix 6.311, Page 220.

N.B. Statistical analysis of this and other models will be done in Section 6.331. Values for expected output calculated by substituting the real data in the model and the actual output from longwall faces are also tabulated in Appendix 6.311, from which graph of Figure 29 is plotted.

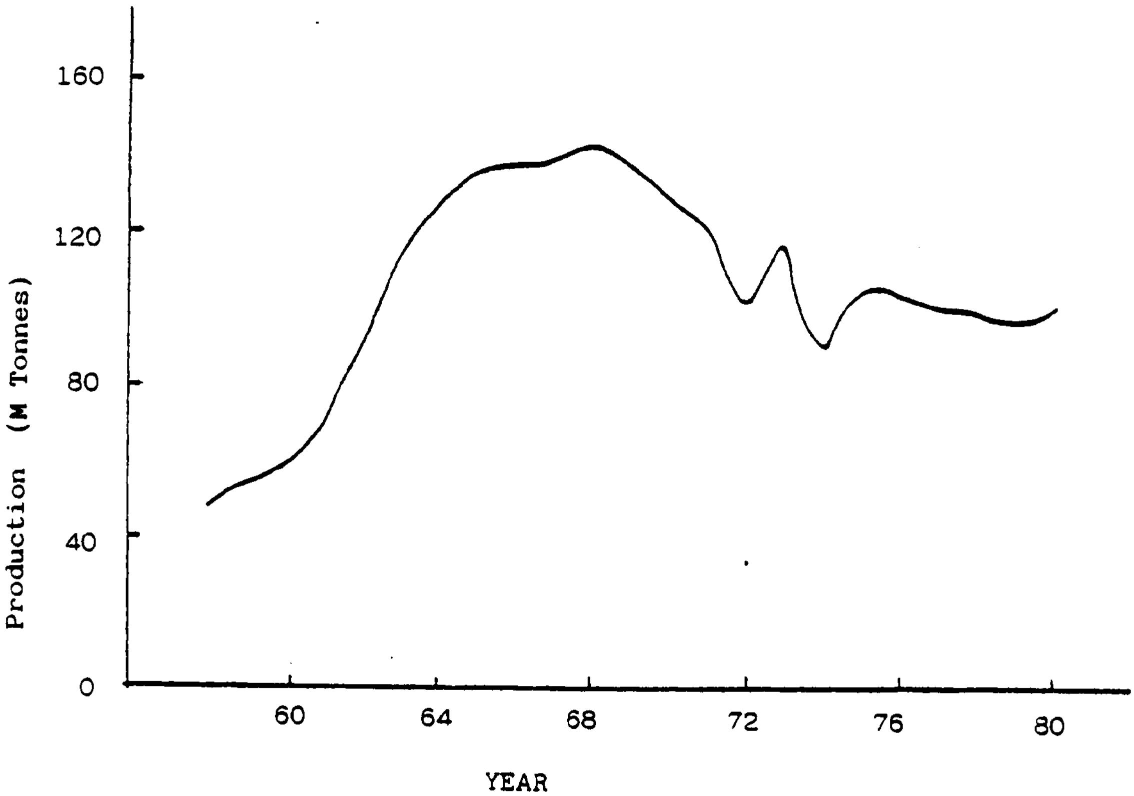


Figure 29 Coal Output 1958-1980

i) Choice of model type:

It is decided that non-linear models will be used throughout this presentation for both output and input components.

Reviewing the literature, it seems that all the work carried out in the past has been centred on linear models. These, advantageous for their simplicity, lack flexibility and accuracy, the latter of which is of much significance here. Non-linear models, on the other hand, although complicated, result in by far more accurate formulae.

ii) Modelling procedure:

In each case, the variables affecting each component were decided upon, and then appropriate powers for each of the variables were found empirically by trial and error. For example, in the case of the output model, it is reasonable to assume that output is proportional to the number of faces, level of technology, seam thickness, number of face days per year and number of face shifts per day, and affected by the dispute tonnage.

$\therefore$ output = $f_1 \cdot f_2 \cdot f_3 \cdots$

Output is expected to be linearly dependent on the number of faces, represented directly by F; the state of technology, T (output per shift); number of face shifts per day, s; and number of face days per year, d. This leads to the expectation that the values of α, β, ω and σ are unity. As regards seam thickness B, the value of γ is expected to be less than one, for it is expected that if seam thickness is doubled, output will rise by less than twofold. Also, trivially, the real output is the potential output less the tonnage of coal lost through disputes (D). These values were tried and each one changed, keeping others constant, to detect the sensitivity of output to each variable, and the accuracy of initial expectations. A value for the constant K which best fits the model was then adopted.

In this process, other mathematical techniques and also some data from N.C.B. areas were used. The six models are therefore the result of tedious, complicated and lengthy procedures, a full description of which would add little to the value of this report.

For full explanation of the modelling procedure see appendix 8.0 (which is inserted in the back cover pocket), page 243.

6.32 Total Inputs

Unlike traditional methods of taking only one input - viz labour, in this study all input components are considered. Furthermore, the cost of inputs is taken to be the measure rather than the physical quantities.

$$\text{Total Productivity} = \frac{\text{Total Output (tonnes)}}{\text{Total Money Value of Inputs (£)}}$$

Total inputs cost is taken to be the sum of five different costs: Labour, Capital, Safety, Power, and Materials and Supplies.

Total Inputs = Labour cost + Capital cost + Safety costs + Power cost + Materials & Supplies cost

Appropriate values for the inflation rate have been used to deflate the obtained values to 1958 prices.

Although overhead costs may affect calculation of total productivity, it would be arguable how to allocate overheads to mechanised longwall coal faces; but in any case, they are not, perhaps, likely to be very dependent on changes of technology. Therefore consideration of overheads has been omitted from this work.

6.321 Labour cost

Labour cost is the money value of all direct and indirect wages paid to coal face workers, at constant prices. It includes benefits paid to those supervisory staff who directly contribute to production but excludes those paid to face end workers.

6.3211 Labour cost model

It is postulated that:

$$W = f\,(F, T, L, p, B)$$

where W is total labour cost at constant prices,
L is the average face length,
p is the number of faces equipped with powered supports,

and plausible that:

$$W \propto F\,T\,L, \text{ and}$$

$$W \propto \frac{1}{p\,B}$$

$$\therefore \quad W \propto \frac{F\,T\,L}{p\,B}$$

or $$W = K\,F^{\alpha}\,T^{\beta}\,L^{\gamma}\,B^{-\phi}\,e^{-\frac{\theta p}{F}}$$

where $K, \alpha, \beta, \gamma, \phi$ and θ are constants.

Substituting

$$K = 3.04 \times 10^{-4},$$
$$\alpha = 0.85,$$
$$\beta = 1.2,$$
$$\gamma = 0.125,$$
$$\phi = 2, \text{ and}$$
$$\theta = 0.25,$$

would give the following formula for direct labour cost:

$$W = 3.04 \times 10^{-4} , F^{0.85} . T^{1.2} . L^{0.125} . B^{-2} . e^{\frac{-P}{4F}} \quad \text{------- } 2$$

The derivation of this model is fully described in appendix 8.0 (which is inserted in the back cover pocket), page 243.

6.3212 Actual Labour Cost

To derive the total labour cost of coal faces the following method has been used:

Labour cost = Total number of manshifts worked x Total wage per shift

$$= \frac{\text{Mechanised longwall output}}{\text{Face output per manshift}} \times \text{Total wage per shift}$$

Once again many adjustments are required - for year, saleable tonnage, wage differentials and the inflation rate.

To adjust for inflation, the index of weekly wage rates for all industries for each year have been taken from "The Monthly Digest of Statistics" for years 1958 - 1969 and the "Main Economic Indicators" for years 1970 - 1980, which themselves needed adjustments.

Values for wage per shift are the national average figures which are readily available in N.C.B. publications for earlier years, but can be derived for later years, and, however, they have been adjusted for wage differentials between face workers and others.

Values for actual labour costs are tabulated in Appendix 6.3212, page 221.

6.3213 Testing the Model

Values obtained for F, T, L, B and p are now substituted in model 2 to test the fit.

i) F, T and B have been discussed before.

ii) L & p are the average length of mechanised longwall faces and the number of faces equipped with powered supports respectively, available in N.C.B. statistics but adjusted for year and major longwall faces.

Using model 2 and the real data obtained for the components of the model, the values for the total face direct labour cost have been calculated, and set against the actual valued derived in Section 6.3212. It should be noted that the model is not expected to hold true for the two strike years, 1972 and 1974. The actual and expected values are tabulated in Appendix 6.3213 from which the graph in Figure 30 has been plotted.

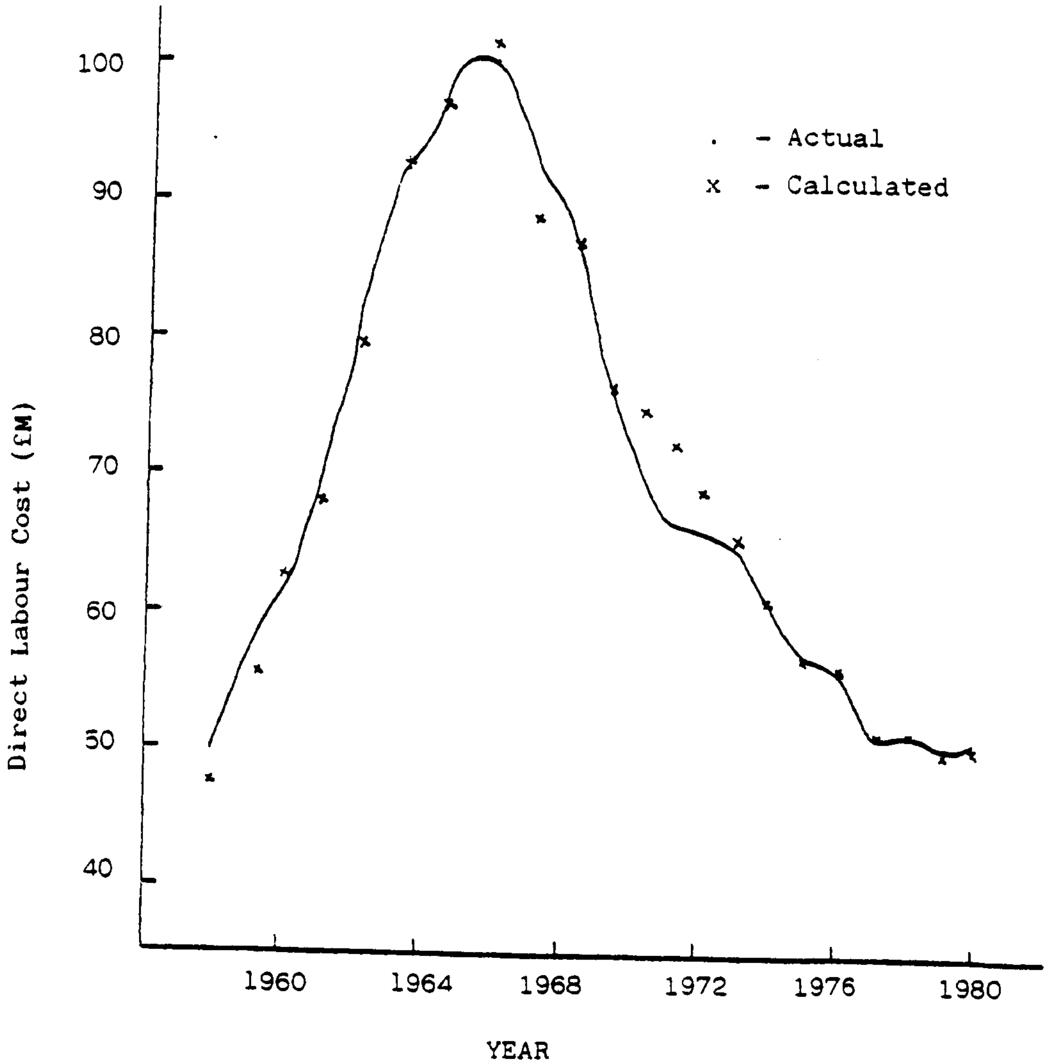


Figure - 30 Actual and Predicted Labour Cost

6.322 Capital Costs

Indeed the most important shortcoming of the present, or OMS measure, is that it ignores capital costs. As a large component of the total inputs cost, and of an increasing trend, most effort has been spent on this component of total productivity, both on its modelling aspect and on derivation of the actual values.

6.3221 Capital Cost Model

It is postulated that:

$$C = f\left[(\text{Quantity, Physical Specifications, Quality, Capacity Utilization, stock) of Capital Equipment}\right]$$

$C_1 = f_1\ (F,\ L,\ p)$	For Quantity
$C_2 = f_2\ (B)$	For Physical Specifications
$C_3 = f_3\ (T,\ R)$	For Quality
$C_4 = f_4\ (P_1)$	For Capacity Utilization
$C_5 = f_5$	For Stock

Verified assumption: Capital Stock is assumed to have been constant from 1958 to 1980, thus f_5 is constant,

and where:

$$C = C_1 + C_2 + C_3 + C_4 + C_5$$

$$C_1 + C_2 = f_6\ (F,\ L,\ p,\ B)$$

$$C_3 + C_4 + C_5 = f_7\ (T,\ R,\ P_1) \times u$$

where u is constant

$$\therefore \quad C_1 + C_2 = K_1\ F^{\alpha}\ L^{\beta}\ p^{\gamma}\ B^{\theta}$$

where K_1, α, β, γ and θ are constants.

Substituting for: $\alpha = 1$

$$\beta = 1$$

$$\gamma = \frac{F}{p \log_e P}$$

$$\theta = \tfrac{1}{2}$$

$$C_1 + C_2 = K_1\ F\ L\ e^{\frac{F}{F}}\ B^{\frac{1}{2}}$$

$C_3 = C_4 = q = f\ (Q) \times u$

where $Q = g\ (T,\ R,\ P_1)$

$\therefore C_3 + C_4 = f \left\{ g\ (T,\ R,\ P_1) \right\} xu$ when $g = K_2\ T^m\ R^n\ P_1{}^b$

then $C_3 + C_4 = f\ (K_2\ T^m\ R^n\ P_1{}^b)\ xu$

where K_2, m, n and b are constants.

Substituting for: $m = 1$

$n = 1$

$b = -1$

$$C_3 + C_4 = f\ \left(K_2\ \frac{T\ R}{P_1}\right)\ xu$$

$$\therefore C_3 + C_4 = K_3\ \left(K_2 \frac{T\ R}{P_1}\right)^{\omega} \times u$$

where K_3 and ω are constants.

$\therefore K_4 = K_2 \times K_3$

Substituting for $\omega = \dfrac{1.17 \log_e (Q - 38) - \log_e 23}{\operatorname{Log}_e Q}$

$$C_3 + C_4 = K_4 \times 1.17^{\frac{Q - 38}{23}} \times u = K_5 \times 1.17^{\frac{Q - 38}{23}} \quad \text{where } K_5 = K_4 \times u$$

$$\therefore C = C_1 + C_2 + C_3 + C_4 + C_5 = K_1\ K_5\ F\ L\ e^{\frac{p}{F}}\ B^{\frac{1}{2}}\ 1.17^{\frac{Q - 38}{23}}$$

$$= K\ F\ L\ e^{\frac{p}{F}}\ B^{\frac{1}{2}}\ q$$

where $K = K_1 \times K_5$ and $q = 1.17^{\frac{Q - 38}{23}}$

Substituting for $K = 5.414 \times 10^{-5}$

$$C = 5.414 \times 10^{-5}\ F\ L\ e^{\frac{p}{F}}\ B^{\frac{1}{2}}\ q \quad \text{..........} \quad 3$$

where $q = 1.17^{\frac{Q - 38}{23}}$

and where $Q = \dfrac{T\ R}{P_1}$

6.3222 Actual Capital Costs

There is much controversy amongst economists as to how to measure capital costs of an organisation. Total productivity analysts have generally taken depreciation values as a measure, due only to the availability of data and the fact that high precision has not been an important factor in their analyses.

Deprec iation values do not obviously represent the actual consumption of capital equipment and even more serious than that, when based on historic costs, as is most often the case, the nominal consumption figures are further distorted. In fact if careful examination of the method used to produce depreciation values, is carried out and comparison between theory and practice is made, these figures may well prove to be meaningless for total productivity measurement. As capital costs in the U.K. coal mining industry constitute a high percentage of the total input costs, and they are increasing, so high precision is required here, since any inaccuracy in the value obtained would distort the results proportionately. For these reasons, depreciation values will not be used in this study for capital costs determination.

Leasing and tilted annuity techniques are not feasible in this case, due to the difficulty of obtaining meaningful data. Also, they include some other costs, such as chargeable interest, which are not of interest here. Furthermore, they measure the VALUE OF SERVICES of capital equipment to ogranisations, while here, the COST of capital equipment to the coal industry is of interest.

The ideal method would therefore be one which would measure the real replacement cost of all capital equipment, whether actually involved in production or not.

The method devised here is theoretically simple, but the main task would be the derivation of the data required.

Total Annual Face Capital Cost = Replacement Cost of Equipment on an Average Face in Each Year x Number of Faces x Constant for Capital Stock ÷ (Average Economic Life of Face Equipment) x Constant for Price Changes.

Faces have been divided into two categories: those with and those without powered supports.

∴ Total Annual Capital Cost = (Cost of each Face with Powered Supports x p) + (Cost of each Face without Powered Supports) (F - p)

$$\times \frac{\text{Constant for Capital Stock}}{\text{Average Life}}$$

x Constant for Price Changes

The factors in this expression are discussed below.

Cost of each Face With or Without Powered Supports

Three sources for obtaining these data have been used:

i) Manufacturers of face main machinary

ii) N.C.B. accounts, and

iii) Other publications, such as those of the Institution of Mining Engineers

In 1980 the cost of equipment on a face with powered supports was about seven times higher than that on a face without powered supports; also in 1958, 19 faces out of 774, as compared with 625 out of 649 faces in 1980, were equipped with powered supports. It is therefore important to consider both types of faces.

In 1958 the cost of equipment on a face with powered supports was only approximately twice as much as those on a face without powered supports and as mentioned above this increased to seven times in 1980. The reason for this is judged to be:

(a) As demand for powered supports as a result of the recognition of their economic and production potential, was increasing, and consequently that for "props and bars" and "hydraulic chocks" was decreasing rapidly after 1958, there has been little or no technological improvement in these equipments, therefore little or no price changes for enhanced quality.

(b) Pressures due to required high outputs, rationalization of faces, replacement of low output/low capital cost faces by high output/high capital cost ones and a need for reduced labour cost on the face, stimulated the technological improvement of powered supports, to the extent that a set of powered supports today hardly resembles one in 1958, either in quality or price.

(c) Faces with powered supports have been required to produce high levels of output in order to justify the high fixed capital costs, and therefore further spending on other-enhanced equipment have not been hesitated, which in turn further widens the gap between the cost of equipping the two different types of faces.

Bearing these factors in mind, the three above sources have been used to obtain the capital cost of a typical face. Attempts have been made to obtain these data from as many of these sources as possible, independently, to allow for comparison and correction of possible errors. It was not, however, possible to derive values, for most years, from all the three sources, but it was thought that at least two sets of data would be required, for these to be of a sufficiently high degree of accuracy. For example for years 1958 -

1962, sources (ii) and (iii) only have been used, while for years 1976 - 1980 a set of data from each of the three sources was obtained.

Constant for Capital Stock (K_1)

For the values obtained for the total capital cost of faces to be realistic, allowance should be made for the value of capital equipment acquired by the coal industry, but not actually in use on the faces. This adjustment is necessary since the values obtained in the above subsection are only the cost of capital equipment in use on the faces. It is conceivable that there is always some equipment which is put out of production for reasons of maintenance, repair and renewals. The coal industry copes with this problem by maintaining a pool of equipment of constant volume, the level of which is slightly higher than that anticipated for use.

$$K_1 = \frac{\text{Money Value of Total Acquired Equipment}}{\text{Money Value of the Equipment in Use}} \left(\frac{C_1}{C}\right)$$

The average mechanised face is now far more capital intensive than in 1958. Therefore, since any interruption in the production process would be highly undesirable, the value of K_1 has tended to increase. On the other hand, since the tendency of equipment towards higher reliability is undeniable, and the number of mechanised faces shows a decrease over most of the period under consideration here, the anticipated required volume of equipment (in terms of the money value) in stock would have a decreasing trend.

To obtain the values of K_1 for each year, an indication was deduced from the total depreciation values from N.C.B. annual accounts together with face data (number of faces, number of machines per face, average face length etc) from the Mechanisation Profile of the N.C.B. However, since this method is too sophisticated for such a small part of the capital cost determination and, as mentioned above, gives only an indication, only a brief description is given here.

Total Value of Capital Equipment (C_1) = Depreciation x Average Life of Machinary

Note that to convert the depreciation values for all mining machinary given in N.C.B. accounts to those for face operations only, large adjustments have been required.

When the effects of changes in F, p, T, L and B are included in C_1, the values obtained for K_1 remain nearly constant. For example, when F increases, the total quantity of equipment would be expected to increase. At the same time the quality of these, reflected by increases in R and T values, also show improvements, itself implying two points: better reliability, hence a decrease in the value of K_1; and higher price, hence an increase in the value of K_1, the resultant of which would cancel to some extent the first effect of increasing F. Also, even an increase in F is not necessarily expected to indicate an increase in the quantity of equipment proportionately, due to the gradual increase in the concentration of mining activities on more major faces, indicated by values of T.

Values for K_1 obtained by this approximate method for the years 1958 - 1980, were between 1.88 and 2.26, implying that 44% to 53% of the total face equipment acquired by the coal industry is actually employed on faces. However, this value is not considered to be of sufficient accuracy; and also, since it is the general policy of this study to produce data from more than one source, in order to eliminate the risk of a major error, these values were checked through several personal interviews and correspondence with the N.C.B. mecahnisation officials and practical mining engineers, as well as by consulting the limited available literature. Stainer[140], for example, in his research, using different methods, arrived at similar results. In this study, therefore, a constant value of 2 will be used for K_1 for years 1958 - 1980.

An interesting fact is, therefore revealed here. It is apparent that taking into account the effect of capital stock on technical productivity, the values calculated in Section 6.23, would become even less, although, for K_1 to have been almost constant, the trend would not be substantially different.

Average Life

By using the average life, the method would tend to incorporate one of the deficiencies associated with using depreciation values, namely the inaccuracy resulted by ignoring the error between the actual and nominal consumption of capital. Since in this Section, however, the past rather than the future is of interest, the nominal values obtained from PAST data are expected to be closer to the actual than in normal accounting procedure. An indication was again derived from N.C.B. accounts using the depreciation values and the money value of all capital equipment in use. These indications were checked through personal interviews and correspondence with N.C.B.

accounting officials and manufacturers as follows.

To summarise the procedure adopted here, values for the average life were obtained from four distinct sources:

i) Accounts - These have generally used between 6 - 8 years for the life of different equipment in different years.

ii) Approximate Theoretical Indicative Method - Mentioned above, this was carried out in a similar way to the one described in the above subsection. This method indicates the average life to have been between 7.2 and 9.4 years.

iii) N.C.B. Mechanisation Personnel - To their judgment, the average life is between 6 and 7.5 years.

iv) Manufacturers - Given the prescribed maintenance, for continuous use, they argue that the average life has always been 7 - 9 years.

For the purpose of this study, all the above figures, except those of source (ii) need first be adjusted for capital stock. It is obvious that, the economic life of machinery out of production would be more than that in production. After adjustment we have:

i)	6.6 - 8.8	Average = 7.7
ii)	7.2 - 9.4	Average = 8.3
iii)	6.9 - 8.6	Average = 7.8
iv)	8.1 - 10.3	Average = 9.2

Given a weight of 0.35, 0.3, 0.2 and 0.15 respectively, the average value would be 8.125. These weights reflect the reliability and relevance of different data to this study.

The value of 8.125, obtained in this way will therefore be used here as the average life of the acquired face equipment , whether in use or not, for years 1958 - 1980.

Constant for Price Changes

As before, a constant is required to allow for price changes. In this case, the index of machinery prices from the Monthly Digest of Statistics, values of which were adjusted for year duration, will be taken to be the appropriate constant.

In this way, values for the total actual face capital cost are calculated, and tabulated in Appendix 6.3222, page 223.

6.3223 Testing the Model

Model 3 of Section 6.3221 is tested here by using actual values for the variables.

T, F, L, B, p have been discussed before.

R is the rate of advance per machine shift of longwall mechanised faces. Its values obtained from the N.C.B. Mechanisation Profile have been slightly adjusted for year definition.

P_1 is the technical productivity whose values were calculated in Section 6.23.

Values of expected capital cost, given by the capital cost model (model 3), together with the actual figures are tabulated in Appendix 6.3223, page 224.

6.323 Safety Costs

This section is dealt with in detail in Chapter 7. The model obtained there is:

$$S = 347 \times 10^{-9} . F^{0.8} . T^{0.8} . s . d . e^{\frac{-1.2P}{F}} \quad .... 4$$

where S is the total safety cost in £ Millions, and other variables have their above meanings.

6.324 Materials and Supplies Cost

Associated with capital equipment there are some additional items necessary, for it to operate efficiently, or at all. Of these, the obvious and most important is the cost of electrical energy to drive cutting/loading machines, the A.F.C. and some other ancillary equipment, which will be discussed in the next section. Other costs, named here Materials and Supplies cost, include the total, labour and material cost of repair and maintenance of face equipment. For a typical longwall retreating coal face, 120 m long, producing 900,000 tonnes of coal pa from a 2.5 m thick seam, the cost of Materials and Supplies in 1978 was £706,500.

6.3241 Materials and Supplies cost Model

It is postulated that:

$M = f(F, d, s, T)$

where M is the total Materials and Supplies cost at constant prices, in £ Millions.

$\therefore \quad M = K F^{\alpha} d^{\beta} s^{\gamma} T^{\omega}$

Substituting for $K = 4.495 \times 10^{-5}$

$\alpha = 1.3$

$\beta = 1$

$\gamma = 1$

$\omega = 1$

$$M = \frac{4.495 \times 10^{-5} . F^{1.3} . d . s}{T} \quad .... 5$$

For full explanation of the modelling procedure see appendix 8.0 (which is inserted in the back cover pocket), page 243.

6.3242 Actual cost of Materials and Supplies

Once again, N.C.B. accounts yield aggregate data for all mining activities and therefore are of little use here. In this case, even colliery records, which give values for faces, are of limited use, since they include the Materials and Supplies cost of face end operations. It is, for example, estimated that 93% of the figure £706,500, mentioned earlier, is attributed to face end operations.

The following sources have been used to derive Materials and Supplies costs for longwall faces:

i) Published data, including old articles of the Institution of Mining Engineers,

ii) Colliery records, mostly of those situated in the Western and Scottish areas of the N.C.B.

iii) N.C.B. Scottish area, mechanisation department.

The focus here has been on the determination of the cost of Materials and Supplies per tonne, from which total cost can easily be calculated. These values are tabulated in Appendix 6.3242.

6.3243 Testing the Model

The actual values of T, F, s and d, all explained in previous sections, are substituted for, in the Materials and Supplies cost model. The resulting values together with the actual costs, are tabulated in Appendix 6.3243. A good fit is observed, but it should be noted that the model is not expected to hold in years with major strikes.

6.325 Power Cost

This is the cost of the electrical energy used to drive machinery, and to provide lighting and communication at the coal faces.

6.3251 Power Cost Model

Formulization of power cost is expected to be relatively simple due to the fact that approximately 95% of the total power consumption is used during actual coal production, i.e. by Shearer/loader, A F C, etc. In other words, there is little fixed power consumption and the amount consumed is to a large extent a function of the output.

It is postulated that: (see appendix 8.0)

$P' = f\,(T, F, s, d)$

where P' is power cost at constant prices in £ Millions, and other variables have their usual meanings.

Again let

$P = K \,.\, T^{\alpha} \,.\, F^{\beta} \,.\, s^{\gamma} \,.\, d^{\omega}$

Substituting for $K = 2.5268 \times 10^{-8}$

$\alpha = 1.22$

$\beta = 0.74$

$\gamma = 1$

$\omega = 1$

$$P' = 2.5268 \times 10^{-8}\, T^{1.22} \,.\, F^{0.74} \,.\, s \,.\, d \quad \ldots\ldots\ldots\ldots 6$$

6.3252 Actual Power Cost

The three following sources have been used to determine face power cost.

i) Available literature, including old articles of the Institution of Mining Engineers and data gathered by Stainer[140] and published in his thesis.

ii) Colliery records: a sample of eight collieries was adopted, mostly in the Western area of the N.C.B. and all producing coal from typical faces.

iii) Accounts of the N.C.B., Scottish area.

Using the values obtained from the above sources, the mean value of power cost per tonne for each year is calculated, from which the total power cost is calculated simply by multiplying it by the total mechanised longwall output.

Having applied normal adjustments, the actual, deflated, power cost figures are tabulated in Appendix 6.3252, Page 227.

6.3253 Testing the Model

Model 6 incorporates T, F, s and d, all of which have been defined, determined and adjusted before. Substituting for these parameters in the model, the expected power cost at constant prices, in £ Millions, is calculated. The values are tabulated in Appendix 6.3253, from which a remarkably good fit is observed. Once again, the values for the two major strike years are not expected to be accurate.

6.33 Total Productivity Model

The total productivity of longwall mechanised coal faces of the U.K. is calculated, as follows: the model for this is:

$$\text{Total productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Tonnage Output}}{\text{Total Inputs Cost}} =$$

$$= \frac{P}{W + C + S + M + P'} \qquad \ldots\ldots\ldots\ldots(7)$$

where: (for any year)

$$P = (0.84 \times 10^{-6}\ F\ T\ s\ B^{\frac{1}{2}}\ d) - D \qquad \ldots\ldots (1)$$

$$W = 3.04 \times 10^{-4}\ F^{0.85}\ T^{1.2}\ L^{0.125}\ B^{-2}\ e^{\frac{-p}{4F}} \qquad \ldots\ldots (2)$$

$$C = 5.414 \times 10^{-5}\ F\ L\ B^{\frac{1}{2}}\ q\ e^{\frac{p}{F}} \text{ where } q = 1.17^{\frac{Q-38}{23}}$$

$$\text{where } Q = \frac{T\ R}{P_1} \qquad \ldots\ldots (3)$$

$$S = 3.47 \times 10^{-7}\ F^{0.8}\ T^{0.8}\ s\ d\ e^{\frac{-1.2\ p}{F}} \qquad \ldots\ldots (4)$$

$$M = 4.495 \times 10^{-5}\ F^{1.3}\ d\ s\ T^{-1} \qquad \ldots\ldots (5)$$

$$P' = 2.5268 \times 10^{-8}\ F^{-0.74}\ T^{1.22}\ s\ d \qquad \ldots\ldots (6)$$

where F is the mean number of longwall mechanised faces,

T is the mean output per shift from longwall mechanised faces in tonnes,

s is the mean number of shifts worked per day on longwall mechanised faces,

B is the mean seam thickness of longwall mechanised faces in metres,

d is the mean number of days per year on longwall mechanised faces,

D is the amount of coal lost by the N.C.B. through disputes in millions of tonnes,

p is the mean number of faces equipped with powered supports,

R is the mean rate of advance of longwall mechanised faces in metres,

L is the mean length of longwall mechanised faces in metres, and

P_1 is the value of technical productivity in percentages,

The above forumla then gives the Total Productivity of longwall mechanised faces for any year in tonnes per £100.

Values calculated for P, W, C, S, M and P' from models (1), (2), (3), (4), (5) and (6) respectively are summarised in Appendix 6.33a, and from these values the total productivity is calculated.

Actual values of P, C, W, S, M and P' derived in Sections 6.31 and 6.32 are tabulated in Appendix 6.33b, and from these figures the actual total productivity is calculated.

The actual and model values for total productivity are tabulated in Appendix 6.33c together with the percentage error between the two.

6.331 Goodness of Fit

All the models derived in Sections 6.31 and 6.32 are tested here for accuracy. The mean and standard deviation of the % error are summarized in Table 15.

$$\text{Mean \% error} = \frac{1}{23} \sum \left| \frac{100\ (A_t - E_t)}{E_t} \right|$$

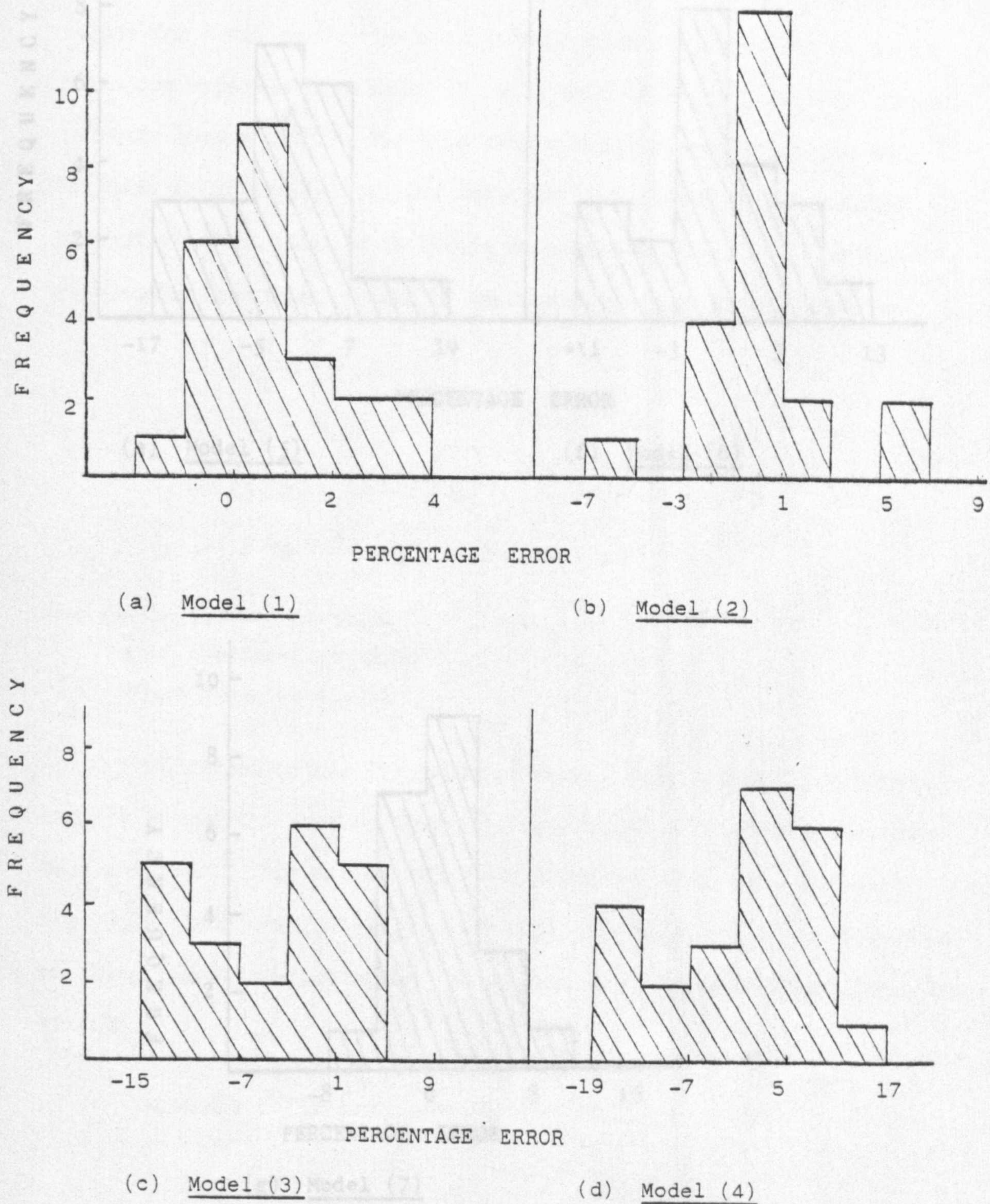
where A_t and E_t are actual and expected values in year t respectively. For models 2, 3, 5, 6 and 7 the two years 1972 and 1974 are excluded.

Model	Mean % Error	Standard Deviation
1	0.95	0.94
2	1.58	1.83
3	5.93	5.13
4	6.97	5.92
5	6.20	5.43
6	4.38	3.43
7	2.94	2.18

Table 15 Accuracy Indicators of Models 1-7

The frequency distributions of the errors in all the models are plotted in Figure 31. The differences between actual and calculated values appear to be satisfactorily small, considering the wide variety of data that are incorporated in the models (see pages 129 - 152). Clearly, there are insufficient points from which to make a meaningful χ^2 test of goodness of fit.

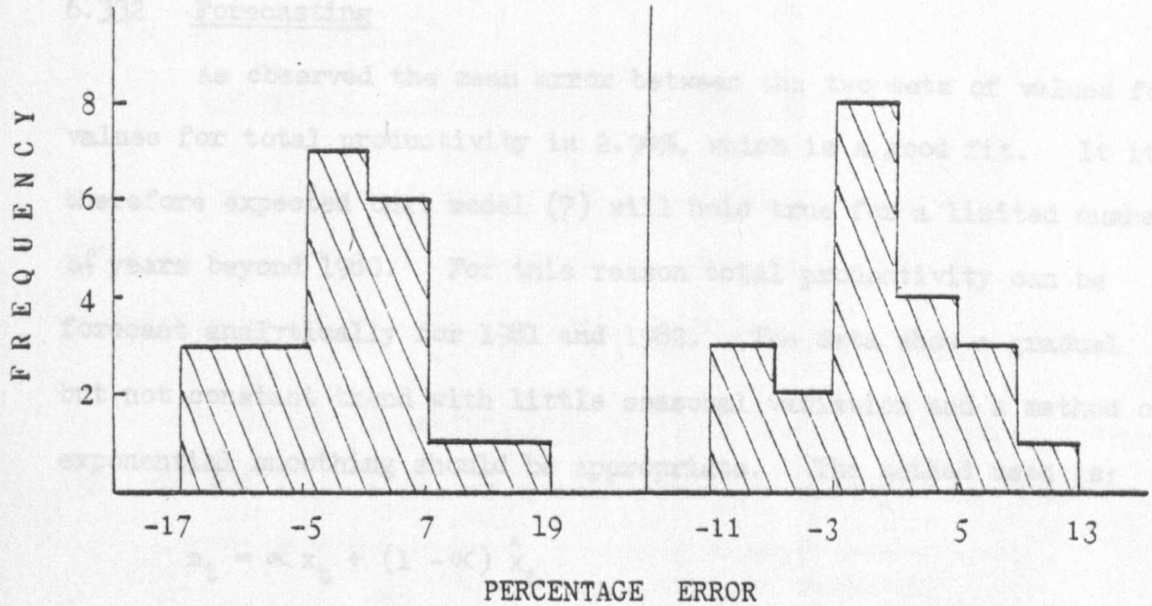
Figure 31



Frequency Distributions of the Errors

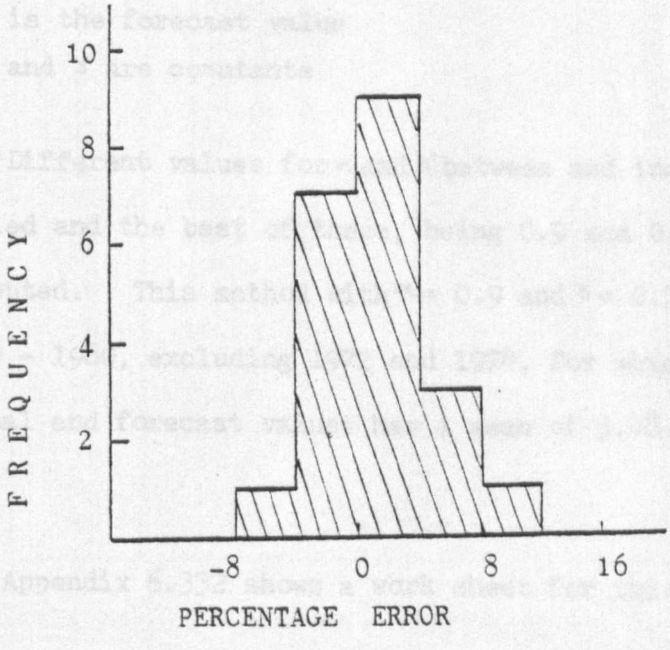
Cont'd

Figure 31



(e) Model (5)

(f) Model (6)



(g) Model (7)

6.332 Forecasting

As observed the mean error between the two sets of values for values for total productivity is 2.94%, which is a good fit. It it therefore expected that model (7) will hold true for a limited number of years beyond 1980. For this reason total productivity can be forecast analytically for 1981 and 1982. The data show a gradual but not constant trend with little seasonal variation and a method of exponential smoothing should be appropriate. The method used is:

$$m_t = \alpha x_t + (1 - \alpha)\,\hat{x}_t$$

$$r_t = m_t - m_{t-1}$$

$$\hat{r}_{t+1} = \gamma r_t + (1 - \gamma)\,\hat{r}_t$$

$$\hat{x}_{t+1} = m_t + \hat{r}_{t+1}$$

where x is the actual value
$\hat{x}$ is the forecast value
α and γ are constants

Different values for α and γ between and including 0 and 1 have been tried and the best of these, being 0.9 and 0.7 respectively, have been adopted. This method with $\alpha = 0.9$ and $\gamma = 0.7$ gives a forecast for 1960 - 1980, excluding 1972 and 1974, for which the % error between the actual and forecast values has a mean of 3.48 and standard deviation of 2.08.

Appendix 6.332 shows a work sheet for this method.

6.333 General Analysis

Comparison of OMS and Total Productivity

The actual values for total productivity, derived in Sections 6.31 and 6.32, and those for OMS available in N.C.B. statistics are plotted against time in Figure 32.

To be more revealing, the ratio of the value for each year to that of 1958 is plotted against time for both measures in Figure 33.

Year	OMS Index	Total Productivity Index	Technical Productivity Index
58	100.0	100.0	314.8
59	102.2	99.8	264.1
60	106.3	102.6	215.2
61	112.4	107.2	219.4
62	119.2	113.0	159.4
63	129.7	127.4	180.2
64	138.2	136.0	191.7
65	144.5	137.4	182.0
66	153.0	137.6	185.7
67	158.8	143.6	158.5
68	166.5	149.6	161.3
69	184.3	161.6	189.4
70	192.0	159.4	168.2
71	198.1	158.0	166.4
72	193.7	149.4	133.6
73	207.7	148.3	156.2
74	200.5	133.1	120.7
75	216.8	142.5	120.7
76	216.8	137.7	117.1
77	212.9	134.6	103.2
78	217.3	128.1	98.6
79	234.3	127.6	99.5
80	244.0	130.9	100.0

Table 16 Comparison of Different Productivity Measures

Figure 33 shows that until only about 1964 total productivity and OMS moved closely together, and since then there has been a considerable difference between the values given by the two measures, supporting the earlier argument that OMS is becoming increasingly misleading as a productivity measurement.

To draw some useful conclusions, the indexed values of technical productivity (see Section 6.2) are also plotted in Figure 33.

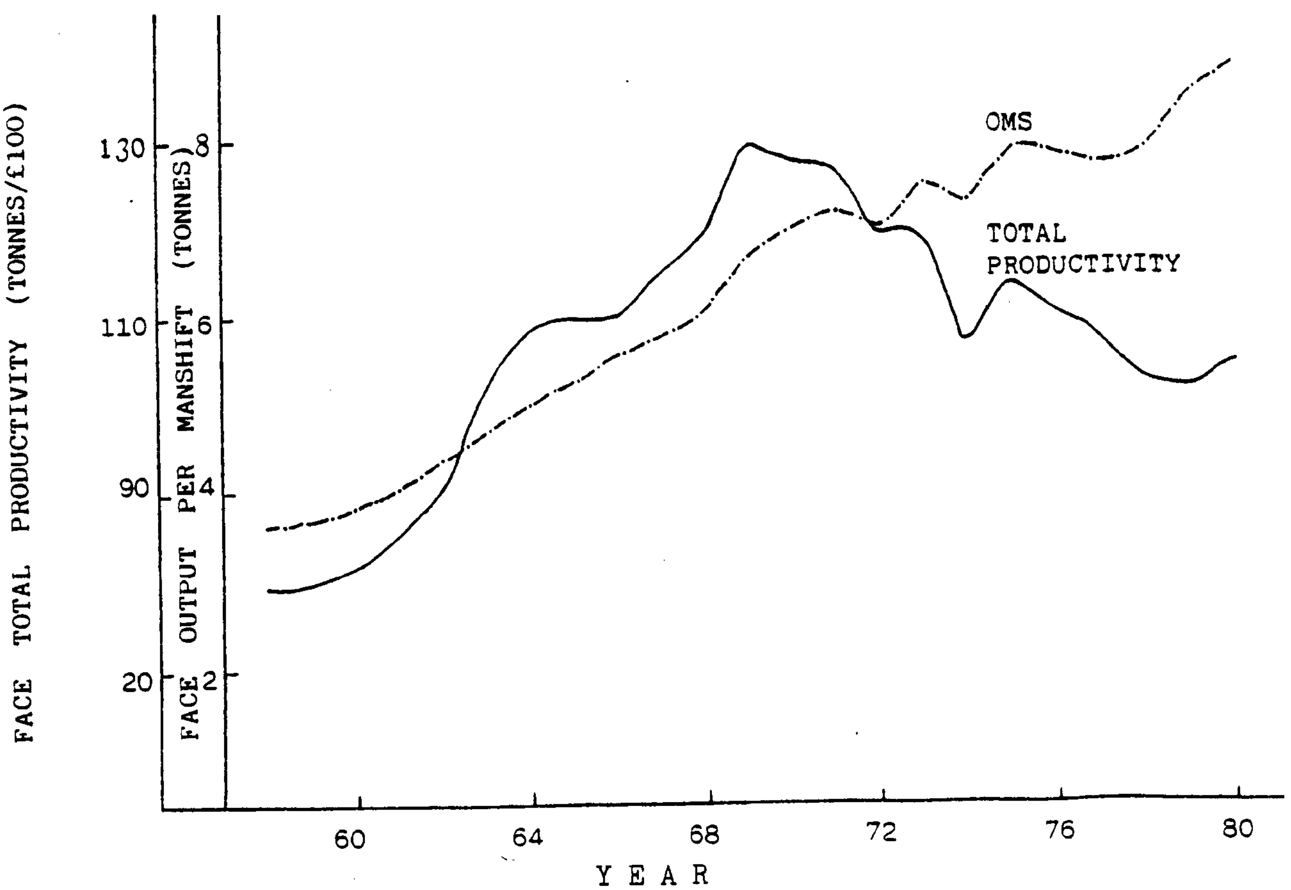


Figure 32 Total Productivity versus OMS

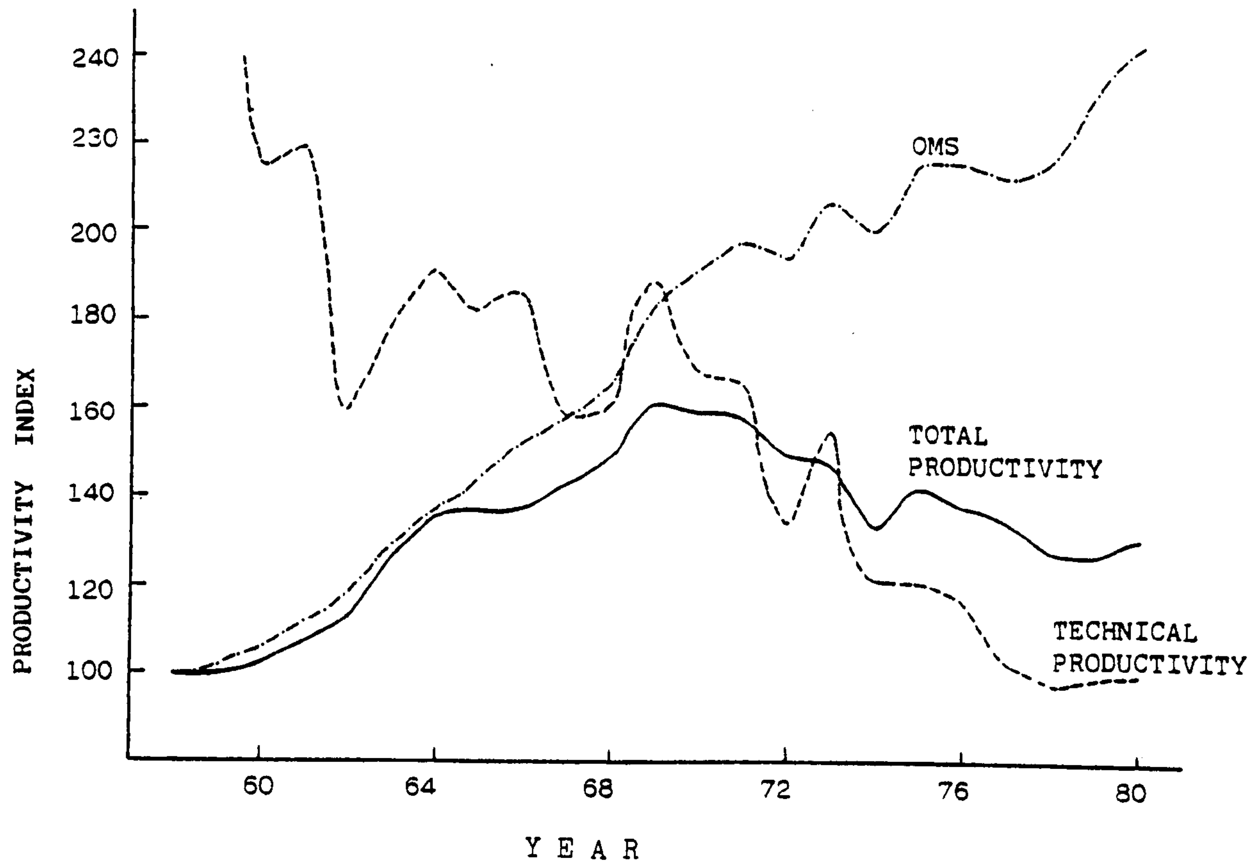


Figure - 33 Index of Productivity Measures

Although values for technical productivity show much fluctuation in the earlier years, from 1969 to 1980, excluding 1972 and 1974 values, the trend is largely decreasing, suggesting that the gap between OMS and total productivity can be filled by using technical productivity values. In other words, the values of OMS produced by the N.C.B. as productivity figures, can be converted to real (total) productivity figures by somehow combining them with technical productivity values, as calculated earlier, and which are relatively simple to derive. The fact that this useful relation holds is not coincidental and can be explained by remembering that technical productivity is in fact indicative of capital productivity and OMS that of labour, and that labour and capital costs together constitute a large part of the total inputs upon which the total productivity measure is based.

It is observed from actual figures that total productivity of longwall coal faces increased by 69.6% from 1958 to 1969, and that from then it shows a gradual decrease, so that the figure for 1980 shows a 30.9% increase over that of 1958. The fact that since 1979 the total productivity of coal faces shows a tendency to increase is undeniable. This is shown by all the three measures, but OMS, expectedly, shows a sharp increase. Total productivity, on the other hand, shows a gradual increase, and even technical productivity seems to have developed. It can therefore be concluded, with a high degree of confidence, that from the technological economics point of view, the productivity of coal faces, after nine years of declining started to increase in 1979. This was to a large extent expected, as it was a declared goal of the 1979 government. OMS values, despite all other indications of low productivity, show an increase every year except 1977.

Comparison of Total Productivity at Different Places in the Mine

Stainer[140] calculated total productivity values for the whole mine for the period 1960 - 1976.* His values, indexed here, are plotted against time together with face total productivity values calculated here, in Figure 34. Looking at the two graphs, a good deal of compatibility between the movements is observed. For example, in both cases the total productivity increases until 1969 when the highest value over the years under consideration is present and after 1969 they both decrease gradually.

* Stainer's years are identified thus: April 1960-March 1961 ≡ 1960; in this presentation: April 1960-March 1961 ≡ 1961.

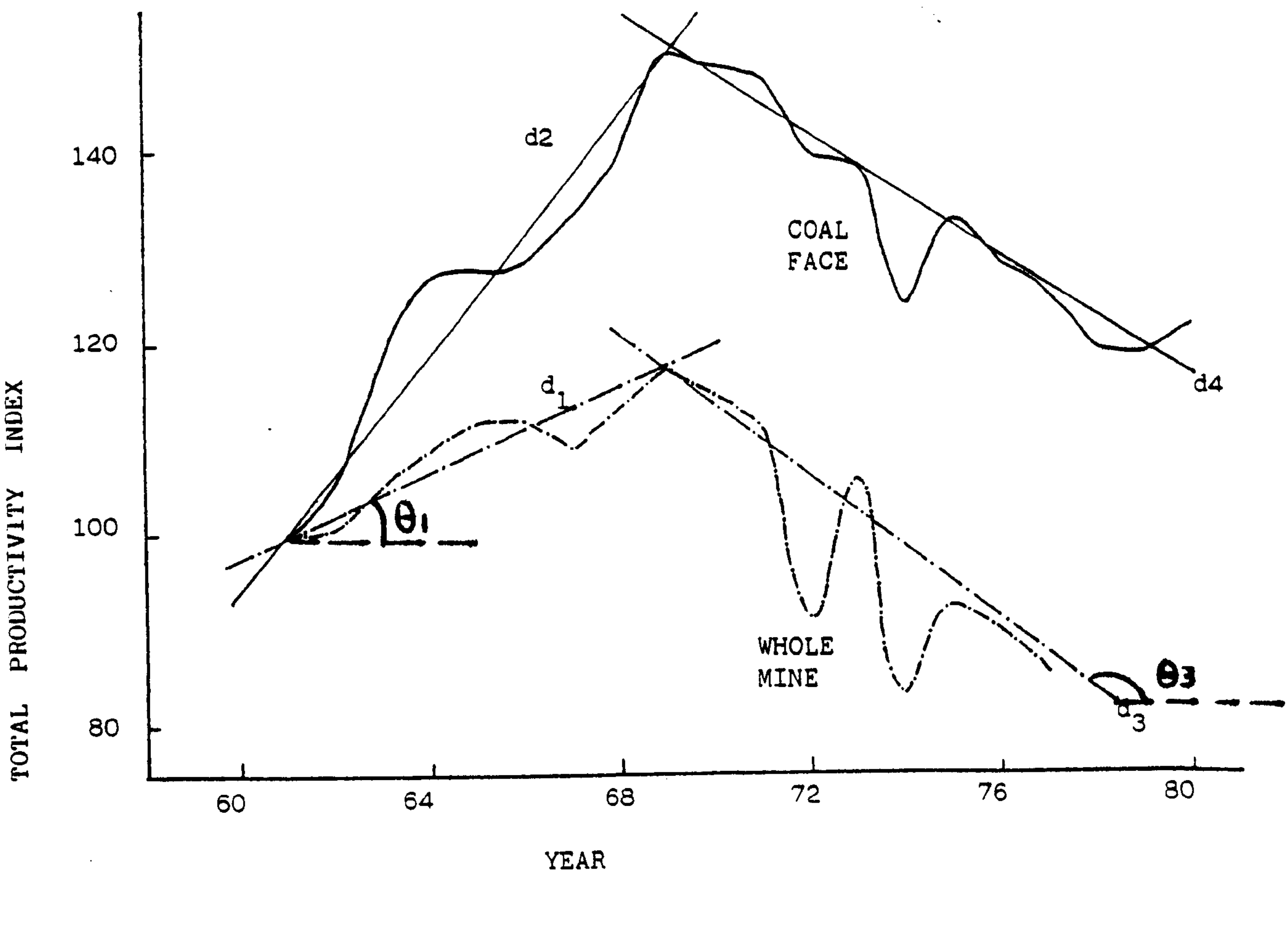


Figure - 34 Productivity of Different Places in the Mines

Year ended March.	Mines total productivity index	Face total productivity index
61	100.0	100.0
62	100.5	105.4
63	105.3	118.8
64	108.9	126.9
65	111.8	128.2
66	112.0	128.4
67	109.1	134.0
68	113.6	139.6
69	117.2	150.8
70	114.5	148.7
71	110.9	147.4
72	91.0	139.4
73	106.2	138.3
74	83.0	124.2
75	92.4	132.9
76	89.6	128.5
77	85.0	125.6
78	-	119.5
79	-	119.0
80	-	122.1

Table 17 Productivity of Different Places in the Mines

It can be observed from the two graphs that the increase for the total productivity of the coal faces has been higher than that for the whole mines and at present coal face productivity stands at a higher level than that for the whole mines, leading to the conclusion that it is now more important to pay attention to other places underground than to the coal face. It is further observed that until 1969, the rate of increase for coal face productivity was higher than that for the whole mines from which can be deduced that until then there were either existing developed methods and techniques elsewhere underground, or simultaneous with the coal faces other places were attended to, since due to the interdependence of the two, improvements in one can always be constrained by the other. Since 1969, the rate of change is more or less constant, meaning that, if there were a tendency for the coal face productivity to increase, it would be constrained by elsewhere underground.

In practice, it is almost impossible for the whole mine total productivity to increase while there is a reduction in face total productivity, due to the common numerator, i.e. output. In other words, productivity of all other places is axiomatically dependent on the productivity of coal faces. This fact is well shown by the graphs.

To be able to draw some explicit and quantitative conclusions, the period is divided into two, 1961-1969 and 1969-1977 and for both, lines d_1, d_2, d_3 and d_4 (see Figure 34) show the average movement of total productivity.

1961-1969:
Slope of $d_1 = 0.46$ therefore $\theta_1 = 25^\circ$
Slope of $d_2 = 1.26$ therefore $\theta_2 = 52^\circ$

1969-1977:
Slope of $d_3 = -0.75$ therefore $\theta_3 = 143^\circ$
Slope of $d_4 = -0.63$ therefore $\theta_4 = 148^\circ$

θ is the angle between line d and the horizontal line.
when $90^\circ > \theta > 0^\circ$ total productivity is increasing.
when $90^\circ < \theta < 180^\circ$ total productivity is decreasing.
when $\theta = 0^\circ, 180^\circ$ total productivity is constant.
when $\theta = 90^\circ$ total productivity is unreal.

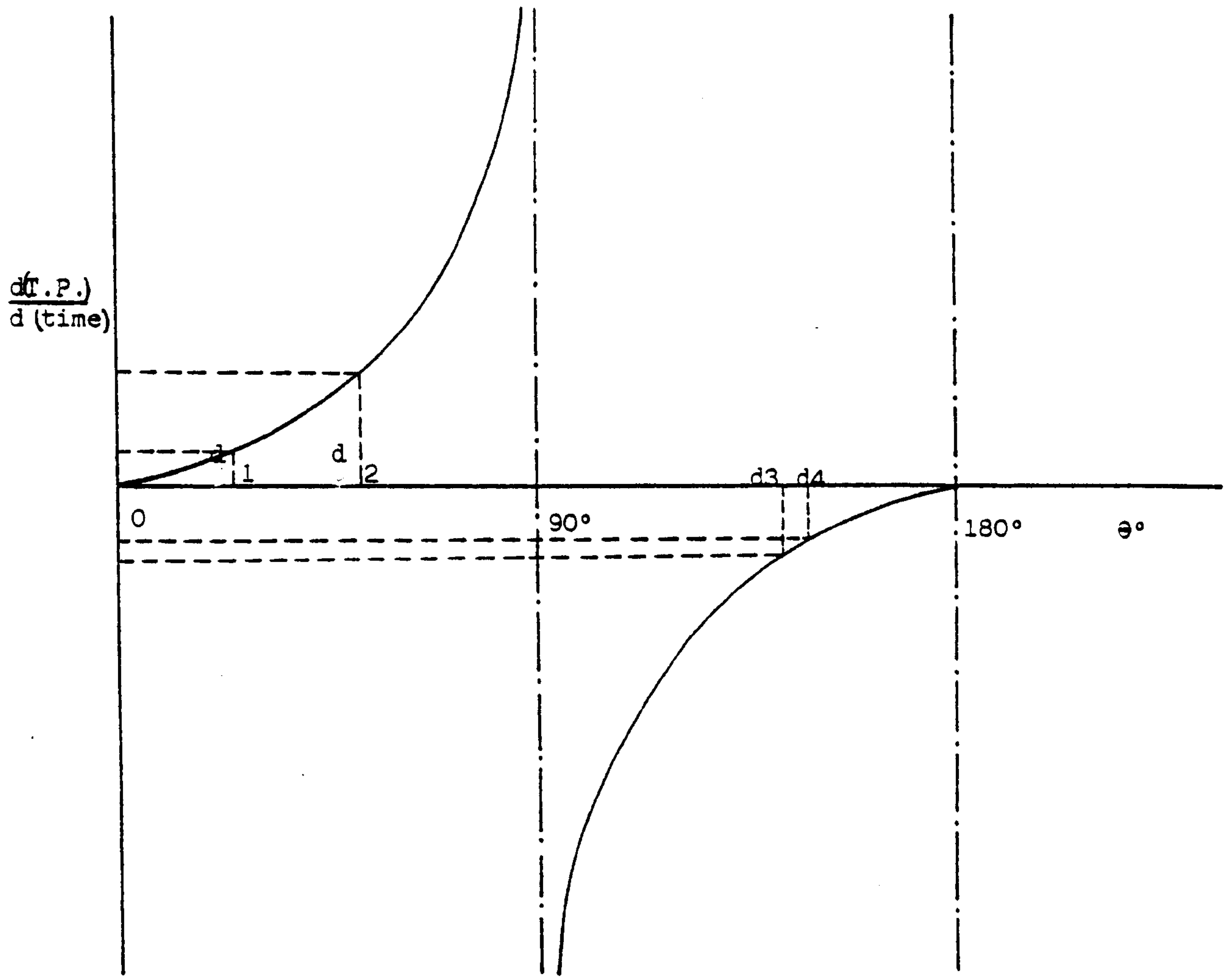


Figure - 35 Analysis of Productivity of Different Places in the Mines

It can be seen from Figure 35 that the higher the value of θ excluding 90° the better the rate of change of total productivity. It is observed from Figure 35 that during the whole period of 1961-1977, total productivity for the coal face has been in a better position than that for the whole mine i.e. a higher rate of increase. Remembering that the whole mine category includes the coal faces, it can be deduced that the increase in the former was largely if not wholly due to the improvements in the latter until 1969, or until then there was little or no improvement made in productivity of other places in the mine than the coal faces. For the years after 1969, the value of θ_3 is still less than that of θ_4, meaning that total productivity of other places in the mine is still lagging behind that of coal faces, but since the value of $(\theta_4 - \theta_3)$ is less than $(\theta_2 - \theta_1)$, it is evident that after 1969, more attention has been given to other places in the mine than in previous years. Further, the difference $(\theta_4 - \theta_3)$ has been small (5°) for the second period which is an encouraging point, for the best practical value for this would be zero, in which case improvements in the level of coal face total productivity would directly result in the level of whole mine total productivity and all production constraints in other areas in coal mines would have been removed.

Total Productivity Components

i) Aggregate Components (total input and total output)

The indexed actual values of total input and total output are plotted against time in Figure 36.

Year ended March	Total output index	Total inputs index
58	100.0	100.0
59	114.9	115.2
60	127.7	124.6
61	150.0	140.0
62	188.0	166.4
63	237.8	186.7
64	264.9	194.9
65	284.9	207.4
66	289.5	210.5
67	291.4	203.0
68	303.8	203.2
69	291.0	180.3
70	267.6	168.0
71	255.9	162.1
72	209.2	140.1
73	245.2	165.4
74	188.9	142.0
75	222.7	156.4
76	219.5	159.5
77	208.8	155.3
78	204.8	160.0
79	202.9	159.2
80	210.7	161.0

Table: 18 Total Productivity Aggregate Components

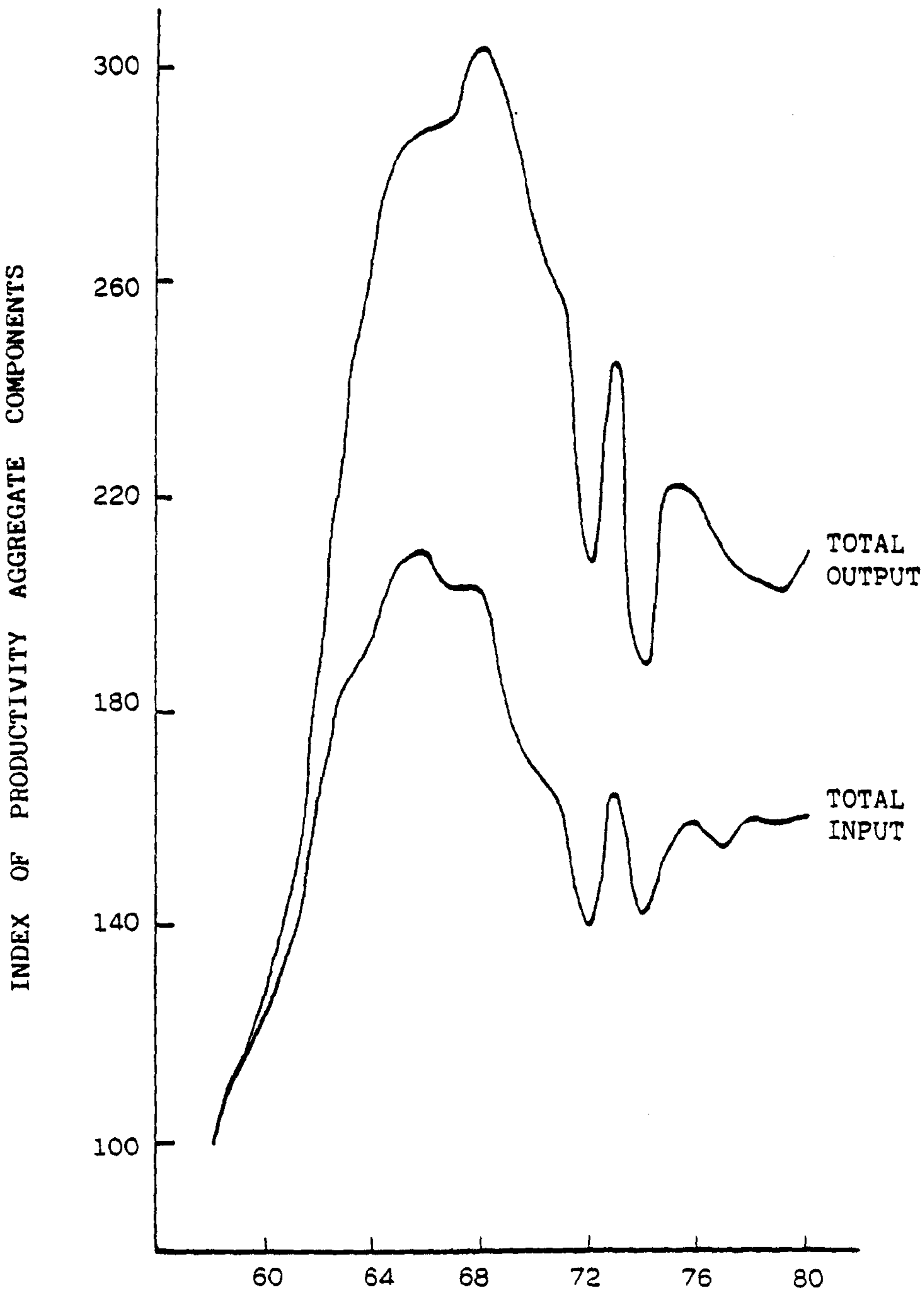


Figure - 36 Total Productivity Aggregate Components

These graphs show the reasons behind productivity movements in slightly more detail, but for full detail a still further analysis is required. However, the two periods of 1958-1969 and 1969-1980 are again noticeable. During the first period, total input rose but the increase in total output was more rapid, which is expected due to the fact that a part of the total input cost is actually fixed, and for this reason total productivity improved. Analytically, in this period, θ for output was greater than for input. For the years after 1969 the decrease in output has been more rapid than input, reflecting the fact that the N.C.B. failed to reduce costs in parallel with the output. The two drops of 1972 and 1974 further emphasize this point, for in both cases output dropped by a higher amount than did input. A distinct period, after 1975, is observed, from the graph of which a frightening fact is apparent, that although output can vary by considerable amounts, total input changes only slightly, and in either direction, reflecting cost inflexibility of coal faces, for which reason coal faces are expected to do well regarding productivity at times of boom and rather badly at times of recessions.

ii) Input Components

Total input is broken here into its components and two sets of ratios are discussed, being the ratio of each component to the total input and that of total output to each component, the latter actually measuring productivity of the corresponding component.

Labour

Values for the indexed ratios of labour cost to total inputs and output to labour cost (labour productivity) are calculated, from which graph of Figure 37 is plotted.

The graph of labour cost per total inputs cost shows a continuous decline, proving the fact that the coal faces have continuously become less labour intensive since 1958.

For the purpose of comparison the graph of OMS has been plotted again, as well as that of the real labour productivity. Labour productivity graph shows an almost continuous increase, like that of OMS, although more recently it has been less rapid. It is apparent from the two graphs that OMS did measure labour productivity until about 1970 with little error, but since then has become increasingly invalid. OMS shows an increase in recent years due to the decrease in the number of men working on the coal faces, while labour productivity reflects the effects of both the number of men and that of wage increases.

Labour productivity, however, seems to have started to increase again despite its drop in 1978 and this together with its general trend should cause the N.C.B. "not to worry too much" about labour productivity. Altogether labour productivity of British coal faces in 1980 shows an increase of 107% over its 1958 level, 13% over its 1969 level and 1.7% over its 1977 level.

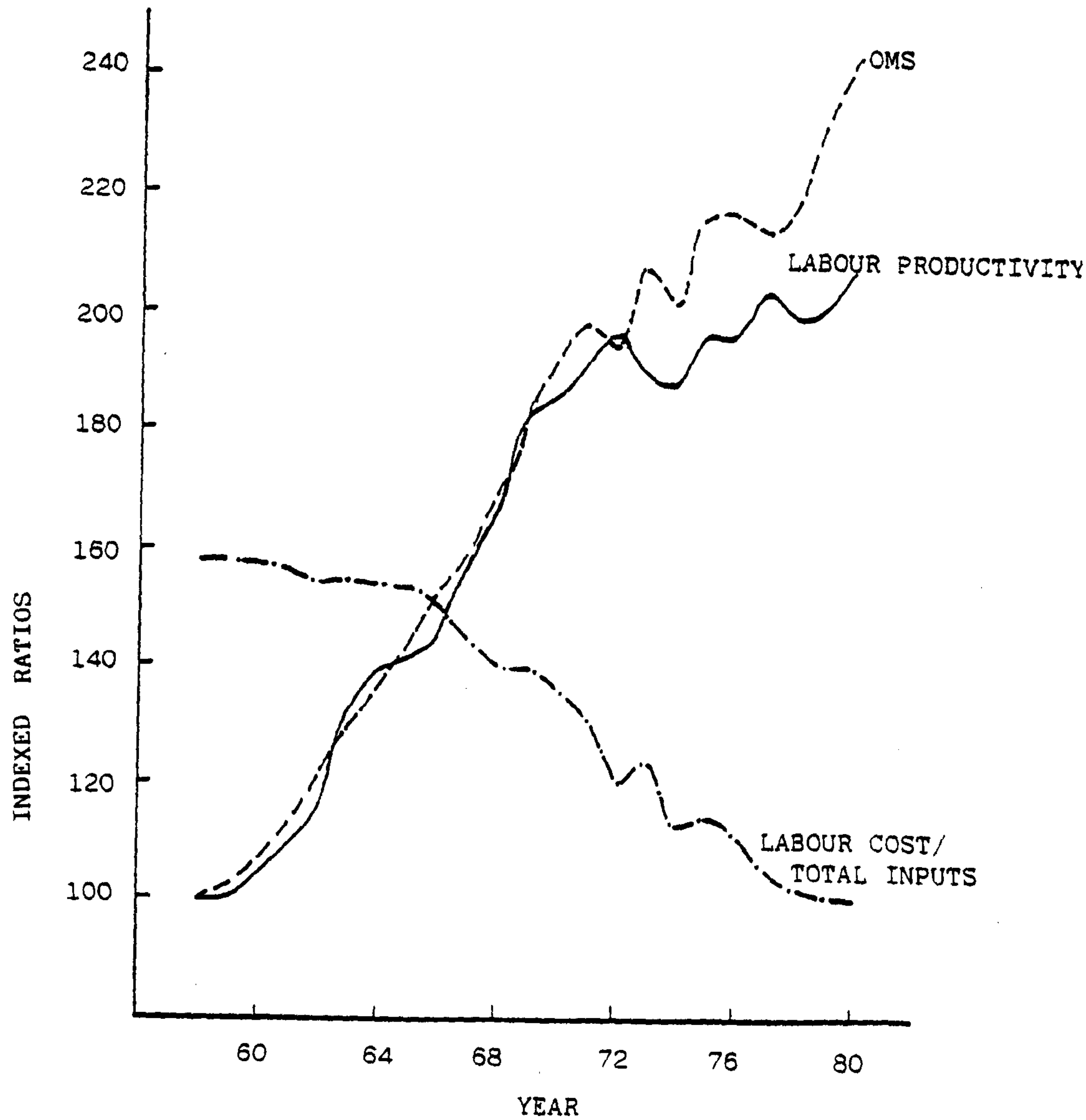


Figure - 37 Analysis of the Labour Cost

Year	Labour cost per total input % age	Labour Productivity (Output per Labour Cost) tonnes/£100	Labour cost per total input Index	Labour Productivity Index
58	84.3	95.2	158.2	100.0
59	84.2	95.1	158.0	99.9
60	83.5	98.5	156.7	103.5
61	83.1	103.6	155.9	108.8
62	82.4	110.1	154.6	115.7
63	82.5	124.0	154.8	130.3
64	81.9	133.2	153.7	139.9
65	81.8	134.8	153.5	141.6
66	80.4	137.4	150.8	144.3
67	77.1	149.4	144.7	156.9
68	74.3	161.5	139.4	169.6
69	74.5	174.0	139.8	182.8
70	72.4	176.8	135.8	185.7
71	69.8	181.5	131.0	190.7
72	64.1	187.0	120.3	196.4
73	66.3	179.4	124.4	188.4
74	59.8	178.6	112.2	187.6
75	61.1	187.0	114.6	196.4
76	59.2	186.6	111.1	196.0
77	55.7	193.7	104.5	203.5
78	54.3	189.2	101.9	198.7
79	53.6	190.8	100.6	200.4
80	53.3	197.1	100.0	207.0

Table 19: Analysis of the Labour Cost

Capital

Figure 38 shows the ratio of capital cost to total inputs and that of output to capital cost (capital productivity). It is apparent from the capital cost/total inputs graph that coal faces are now much more capital intensive than in 1958. The graph has an increasing trend over almost the whole of the period, showing that every year a higher percentage of the total budget than that of previous years was spent on capital equipment. This is not necessarily either advantageous or disadvantageous, and to take analysis further the capital productivity graph is considered. For most of the period this shows a decrease which has been the main limiting factor for total productivity improvements.

The decreasing trend of the capital productivity should warn the N.C.B., and should cause some awareness of profitability of capital investments. In order to improve this, more thorough studies of the profitability of investments should be carried out, and the cost factor should seriously be considered when making such decisions. Capital equipment has mainly been acquired to bring about savings in labour cost, but comparing the graphs of capital productivity and labour productivity it is apparent that in the years beyond 1969 additional expenditures have been greater than resultant savings(figures 37 and 38).

Comparing capital productivity values with those of technical productivity would serve as a check for both measures. In 1980 capital productivity was 66.95% higher than its level in 1958 while the corresponding figure for technical productivity was 68.23%.

Year	Capital cost per total inputs % age	Capital Productivity tonnes/£100	Capital cost per total inputs index	Capital productivity index
58	11.1	725.6	100.0	302.6
59	11.4	700.4	102.7	292.1
60	11.9	690.1	107.2	287.8
61	12.4	695.9	111.7	290.2
62	13.2	687.4	118.9	286.7
63	13.0	785.6	117.1	327.6
64	13.3	818.3	119.8	341.2
65	13.6	812.0	122.5	338.6
66	15.0	738.5	135.1	308.0
67	18.4	625.6	165.8	260.9
68	21.2	565.7	191.0	235.9
69	21.0	617.5	189.2	257.5
70	23.5	543.5	211.7	226.6
71	26.1	484.7	235.1	202.1
72	32.1	373.6	289.2	155.8
73	30.2	394.5	272.1	164.5
74	36.7	290.9	330.6	121.3
75	35.5	321.6	319.8	134.1
76	37.4	295.7	336.9	123.3
77	41.0	263.4	369.4	109.8
78	42.6	241.1	383.8	100.5
79	43.3	236.6	390.1	98.7
80	43.8	239.8	394.6	100.0

Table 20: Analysis of the Capital Cost

The only slight difference of decrease between the two measures of productivity, which as noted in previous chapters started with entirely different concepts, took different lines of approach and were calculated by quite different methods, provides a check on the calculations and data. (See table above and page 158)

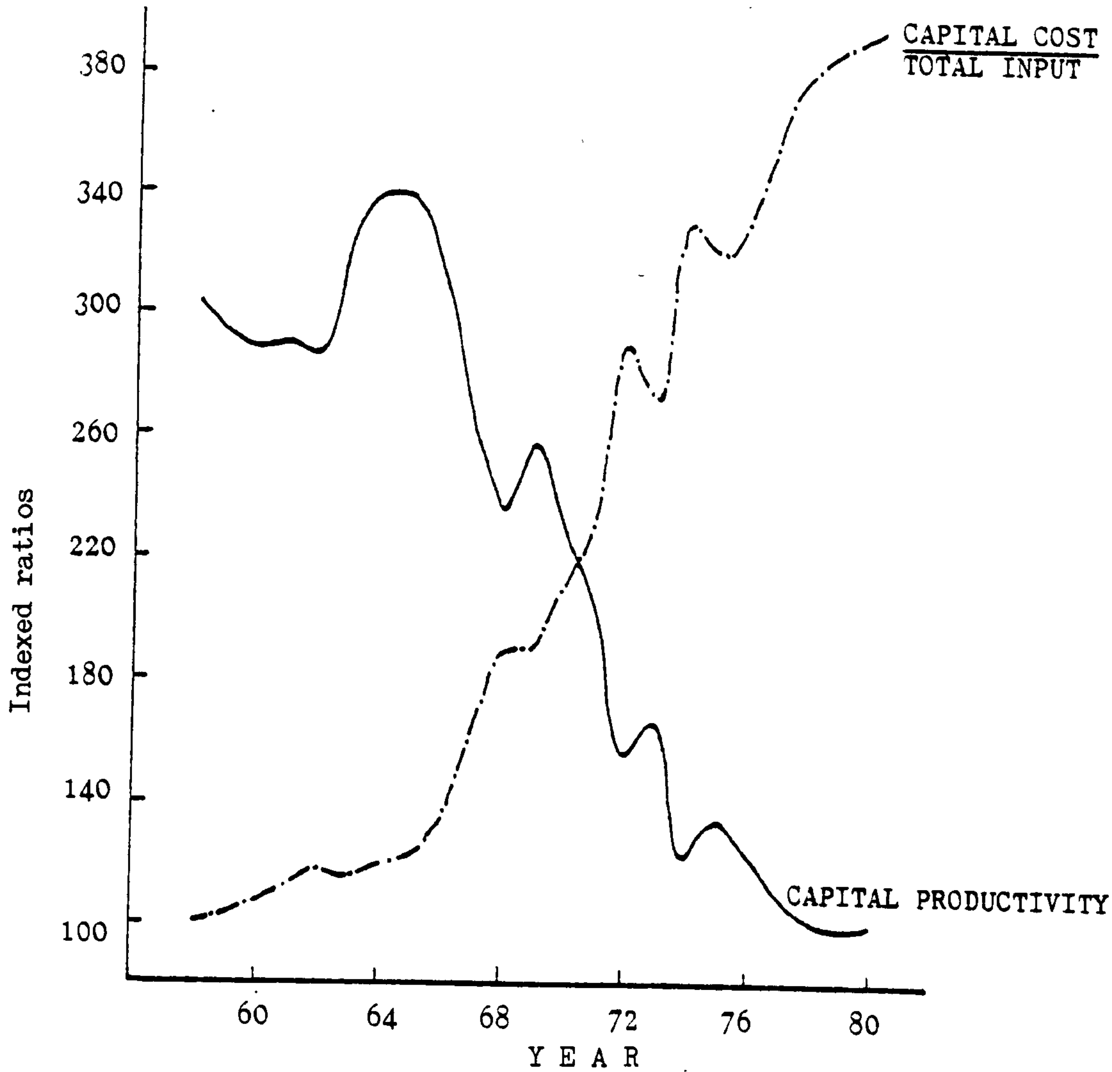


Figure 38 - Analysis of the Capital Cost

It can be concluded from the two above points, i.e. the compatibility of the capital and technical productivity graphs and their decreasing trend, that the latter is mainly due to the fact that capacity utilization has become increasingly low, leading to the recommendation being made to the N.C.B. that more emphasis should be put on higher exploitation of the already acquired equipment, than on the purchase of new machinery. Increasing the number of shifts worked per day, number of days per year and both machines available time and machine running time would be of great help to reverse the situation.

Safety, Materials and Supplies, Power

Safety figures will be produced in Chapter 7 where it will be done separately and in more detail.

Year	Materials and Supplies: Cost per total input % age	Materials and Supplies: Productivity tonnes/£	Materials and Supplies: Cost per total input index	Materials and Supplies: Productivity index	Power: Cost per total input % age	Power: Productivity tonnes/£	Power: Cost per total input index	Power: Productivity index
58	0.83	96.9	100.0	100.0	1.12	71.47	100.0	100.0
59	0.88	91.3	106.0	94.2	1.04	77.15	92.9	107.9
60	0.94	87.7	113.3	90.5	1.05	78.65	93 .8	110.0
61	1.02	84.5	122.9	87.2	1.14	75.72	101.8	105.9
62	1.04	87.1	125.3	89.9	1.23	73.72	109.8	103.1
63	1.06	96.5	127.7	99.6	1.36	75.47	121.4	105.6
64	1.04	105.0	125.3	108.4	1.49	73.02	133.0	102.2
65	1.02	108.6	122.9	112.1	1.53	72.17	136.6	101.0
66	0.98	113.0	118.1	116.6	1.56	71.00	139.3	99.3
67	0.91	126.8	109.6	130.9	1.58	73.12	141.1	102.3
68	0.87	137.7	104.8	142.1	1.75	68.66	156.3	96.1
69	0.77	168.7	92.8	174.1	1.97	65.64	175.9	91.8
70	0.61	209.9	73.5	216.6	1.93	66.42	172.3	92.9
71	0.60	211.5	72.3	218.3	1.91	66.20	170.5	92.6
72	0.52	230.0	62.7	237.4	1.83	65.61	163.4	91.8
73	0.45	266.4	54.2	274.9	1.82	65.41	162.5	91.5
74	0.39	273.3	47.0	282.0	1.69	63.27	150.9	88.5
75	0.45	253.6	54.2	261.7	1.75	65.31	156.3	91.4
76	0.46	241.9	55.4	249.6	1.72	64.07	153.6	89.6
77	0.45	238.9	54.2	246.5	1.71	63.15	152.7	88.4
78	0.39	261.4	47.0	269.8	1.66	61.79	148.2	86.5
79	0.36	283.3	43.4	292.4	1.68	60.91	150.0	85.2
80	0.32	324.6	38.6	335.0	1.72	61.01	153.6	85.4

Table 21 Analysis of Materials & Supplies and Power Costs

Figures 39 and 40 show the above information for materials and supplies and power respectively.

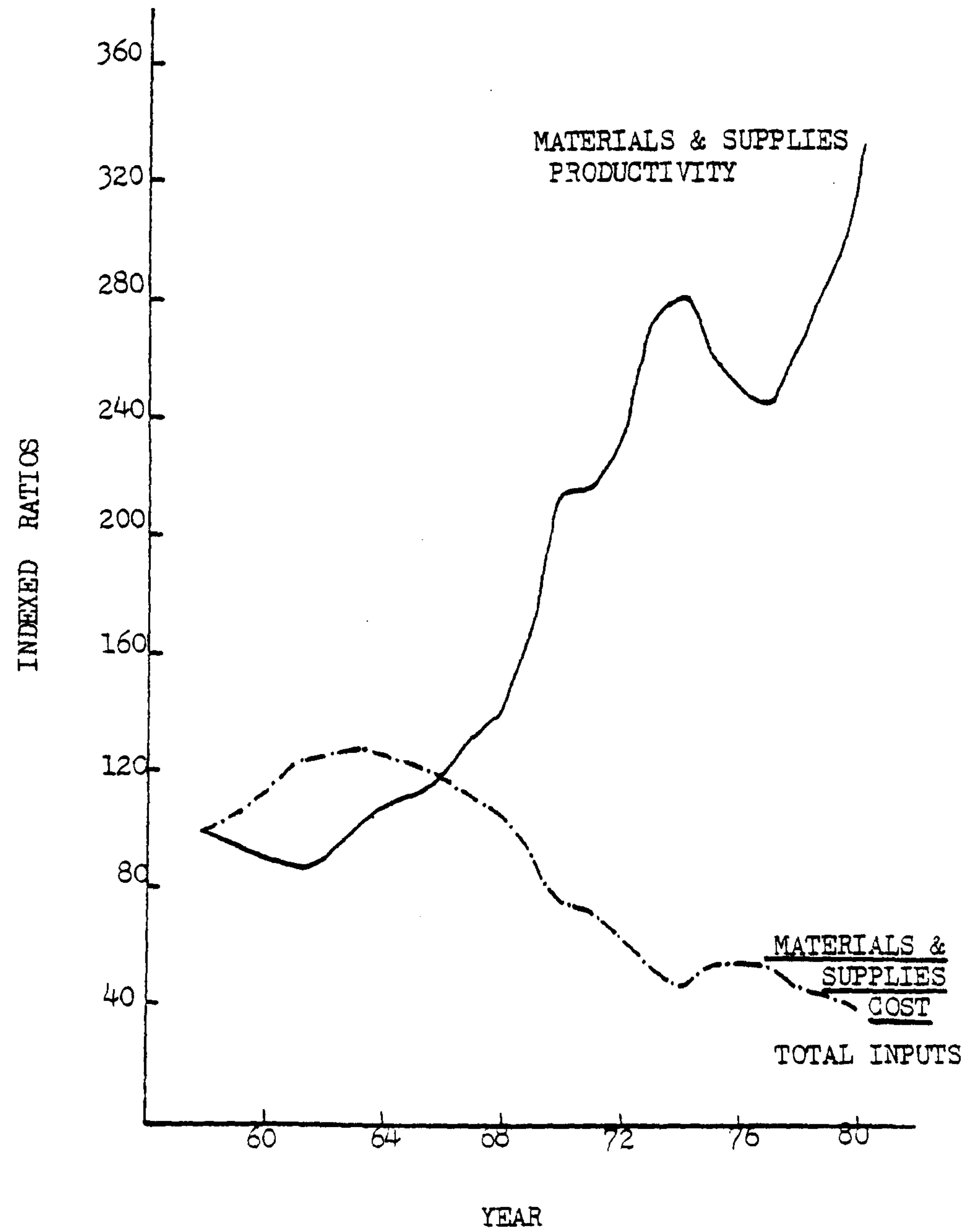


Figure 39 Analysis of Materials & Supplies Cost

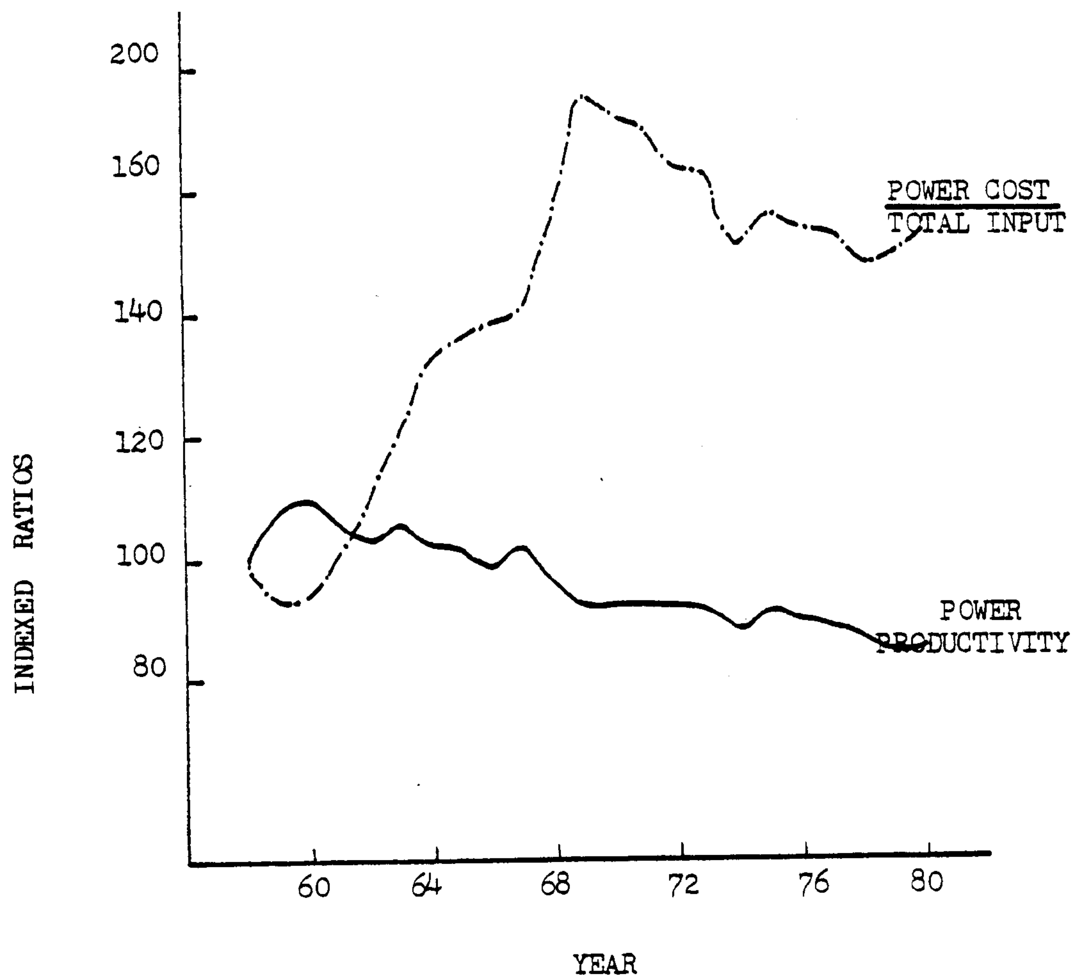


Figure 40: Analysis of Power Cost

It can be seen that materials and supplies cost constituted only between 0.32% and 1.06% of the total inputs cost, hence of little significance regarding productivity movements. This ratio has decreased by 61.4% from 1958 to 1980. Materials and supplies productivity shows a good improvement too, being 335%, which is a reflection of more reliable and hence more expensive machinery in use.

From these, it seems that the importance of materials and supplies productivity has been overestimated to the extent that it has been brought about at the expense of capital productivity.

Power cost also constitutes a small part of the total input, although in 1980, 1.72% of the total cost was for this, which is over five times more than that for materials and supplies.

The two graphs for power (Figure 40) do not reveal any important point and they rather confirm some expected facts. The increase in the ratio of power cost to total input until the early 1970's was due to the increase in output and intensity of mechanisation, while the small decrease after that reflects the usage of more efficient machinery and the decrease in output.

Power productivity, expectedly, does not show much fluctuation or trend, due to the fact that, as mentioned before, a large part of the power cost is directly proportional to the output. Small fluctuations hence to a large extent indicate changes in cost per unit while the general gradual downward trend confirms more intense usage of ancillary equipment such as methane drainage, better lighting and communications and dust supression techniques.

7. QUANTIFYING SAFETY IN COAL MINING

7.1 INTRODUCTION

The number of men affected by serious accidents on longwall faces was approximately five times lower in 1980 than in 1958. Can it be concluded that from the TECHNOLOGICAL ECONOMICS point of view, safety on the faces is now five times better than it was in 1958? This is the question to be investigated in this chapter.

A great deal has been written about safety in coal mines since the beginning of the century. Almost all of the available literature centres on the following points:

(a) Social effects of accidents, both on those directly affected, and on the community as a whole.

(b) Measuring the frequency of occurrence of accidents and producing RAW statistics, although recently the rate of accidents per manshift worked has also been considered.

(c) Recommendations as how to manage and improve safety.

Only since 1976, a few authors, notably Collinson[145] and Beddoe[97], have made attempts to estimate the cost of accidents, but only to emphasize the importance of safety. The VERY BRIEF articles they have produced, are far from being comprehensive.

In this chapter, social effects of the occurrence of accidents are not considered. The aim is to quantify cost of accidents to the coal industry, whilst not deriding attempts to assess other effects.

Definition of Accidents

Accidents are defined here as those unplanned events, in which one or more persons are involved, leading to a sort of DIRECT financial cost to the coal industry.

The word "direct" is added to imply that the indirect costs, such as the loss of output due to an accident, are not included, but wages paid to men temporarily unproductive as a result of an accident are included.

Furthermore, the definition seems to include disease infection cases, for they are unplanned and often lead to financial cost. For simplicity, these will also be classed as accidents here, although in the mining industry they are often referred to as "incidents".

7.2 MEASUREMENT

7.21 Safety Cost Model

It is expected that safety cost is a function of output and the state of technology. Output itself is a function of concentration of workings and the total number of manhours worked on the face.

Therefore, $S = f(F, T, s, d, p)$

where S is the total safety cost per year
F is the number of longwall mechanised faces,
T is the output per shift from longwall mechanised faces,
s is the mean number of shifts worked per day,
d is the mean number of days worked per year, and
p is the number of faces equipped with powered supports.

Put $S \propto F^{\alpha} . T^{\beta} . s^{\gamma} . d^{\omega} . p^{\varepsilon}$

or $S = K F^{\alpha} . T^{\beta} . s^{\gamma} . d^{\omega} . p^{\varepsilon}$

where K, α, β, γ, ω and ε are constants.

Substituting for $K = 347 \times 10^{-6}$

$\alpha = 0.8$

$\beta = 0.8$

$\gamma = 1$

$\omega = 1$

$\varepsilon = \dfrac{-1.2\ p}{F \log_e p}$

$$\text{then } S = 347 \times 10^{-6}\ F^{0.8}\ T^{0.8}\ s\ d\ e^{\frac{-1.2\ p}{F}} \qquad \ldots\ldots\ldots\ldots 4$$

For full explanation of the modelling procedure see appendix 8.0 (which is inserted in the back cover pocket), page 243.

7.22 Actual Safety Cost

As mentioned earlier, safety is measured here by the cost of its reciprocol i.e. accidents.

$$\text{Safety} = \frac{1}{\text{Accidents Frequency}}$$

Cost of Accidents = Number of Accidents x Cost per One Accident

Accidents are divided into four categories: Fatal, Serious Minor and Disease infections.

7.221 Fatal Accidents

Number of Fatal Accidents on Longwall Faces

Available statistics mostly give the number of accidents for all different places in mines. From these the number of accidents occurring on the longwall faces is derived.

Face Fatal Accidents = Total Fatal Accidents x Constant

Statistics of the total number of fatal accidents are readily available, although cases of inconsistency are observed between the two main sources used, namely, Reports of the Chief Inspector of Mines and Quarries, and, the annual Reports of the chief safety engineer of the N.C.B., in which cases, the mean is taken to be the true value.

Accidents on the longwall faces have been subdivided into those caused by:

(i) Falls of Ground - For this category, the number of fatal accidents occurring on the longwall faces are available, there is therefore no need for the constant to be used.

(ii) Transport - For accidents caused by transport equipment and in handling devices, only the total is available and the constant is required to convert these to those actually happening on the longwall mechanised faces. For this category, it is estimated that a constant of 0.2 for 1958, gradually decreasing to 0.15 in 1980, is appropriate.

NOTE - Adjustments have also been made to convert the total number of accidents for all mines, to the longwall mechanised faces only, as well as for year definition. Figures given here are therefore substantially different from those in the above sources.

(iii) Machines - These are accidents caused by machines such as the shearer loader on the longwall faces. The usual adjustments have been carried out. Use of the constant is necessary for most years, and is taken to be the mean of the constant for years 1973-1978, for which it can be calculated directly.

(iv) Miscellaneous - These are accidents caused by all sources but the above three. The usual adjustments and the constant are necessary.

The total number of fatalities on the longwall mechanised faces, derived in this way, are tabulated in Appendix 7.221a.

<u>Cost per case of Fatal Accidents</u>

It is common knowledge amongst economists and cost benefit analysts that evaluation of a man's life is a difficult task. Different points of view can be taken, each of which can give very different results. For the purpose of this study, however, only the financial cost incurred by the industry, as a result of a man being killed in an accident, is considered. It is admitted here that these values may well be far from similar to any others, obtained as a result of taking a different point of view and therefore being based on different assumptions.

The direct financial losses to the coal industry due to a fatal accident on the longwall face, are divided into three categories:

(i) Common Law damages and compensation - This is the amount of money paid directly to the victim's family. The amount paid depends on many factors, such as the age of the victim number of children, salary before the accident etc. The mean of the amount paid in each year, which was obtained from N.C.B. safety officials reports and accounts and the National Union of Mineworkers records, is taken to be the required value.

(ii) Replacement Cost - For a man to be considered competant to work on the coal face, a certain number of shifts are necessary to have been done elsewhere underground. Normally when a new worker is employed, after 120 shifts (six months) he could be classed as a face worker. During these 120 shifts, he receives his full wages while his time is spent on training and working. For example, the first week of employment is spent only on visiting different places in the mine, both underground and on the surface (during which time his productivity is almost zero). Assuming that during this period his productivity is 50%, implies that £ (60 x wage per shift) is spent on a man for him to become skilled enough to work on the face. As a result of any fatal accident, a man should be trained for replacement, the cost of which is taken into account here. Although this is not carried out in the above manner by the N.C.B., by considering the cost of maintaining a constant pool of skilled men to replace possible fatalities, the above simplification seems reasonable. The number of shifts carried out unproductively shows a slight increase over the period.

(iii) Other Costs - These are all costs but the above two such as clerical costs etc. The value of these, being relatively small, has been estimated through personal interviews and consulting the limited available literature.

Values obtained for these three categories are tabulated in Appendix 7.221b, page 234.

Total Cost of Fatal Accidents

In this way, the total cost of fatal accidents to the coal industry is calculated by simply multiplying the number of accidents by the cost per case, and tabulated in Appendix 7.221C, page 235.

7.222 Serious Accidents

Serious accidents are defined here as those major accidents which are likely to endanger life, cause permanent incapacity for work or substantially impair efficiency, for example, fractures of skull, spine, arm or leg; dislocation of shoulder or knee; amputation of hand or foot; or loss of sight of an eye.

Number of Serious Accidents

As in the case of fatal accidents, attempts are made to derive the number of serious accidents directly from published statistics where possible. Otherwise, the constant is used again, as in the case of fatal accidents. Serious accidents are also divided into four categories:

(i) Falls of Ground - numbers in this category are available from N.C.B. statistics and the Health and Safety Executive reports.

(ii) Transport - Values can be directly taken from N.C.B. statistics for years 1973 - 1978, and for other years, and for other years, the constant has been used with its value as found from years 1973 - 1978.

(iii) Machines - As for (ii).

(iv) Miscellaneous - The number of all other serious accidents has been derived by the use of the constant (the same as those in 7.221(iv) and the total number of accidents, available in Health and Safety Executive reports.

All the above figures, which have been adjusted for year definition and longwall mechanised faces, are tabulated is Appendix 7.222a, Page 236.

Cost per case of Serious Accidents

(i) Serious accidents often lead to physical disabilities, for which compensation and common law damages have to be paid by the coal industry. Table 22 shows compensation and common law damage values[163] payable in 1979.

Accidents resulting in	C/L Dam. & Comp. (£)
Paraplegia	30,000
Loss of an eye	6,000
Leg amputation above the knee	16,000
Leg amputation below the knee	10,000
Arm loss	12,000
Hand loss	9,000
Thumb loss	2,500
Index finger loss	2,000
Little finger loss	1,000

Table 22: Source: Reference number 163.
Common Law Damages and Compensation in 1979

The mean of different amounts paid, per case, for compensation and common law damages in each year has been estimated, using the limited available literature and the N.U.M. records.

(ii) There are some other costs, although small, associated with serious accidents. The victims of this type of accident, almost in every case, leave the coal face, therefore replacement costs are as described in the case of fatal accidents. Wage charges in some cases, medical attention costs, additional clerical effort costs, etc. are all examples of these minor direct costs. For simplicity, the sum of all these is tabulated in Appendix 7.222b under "other costs". Also, it is assumed that these costs are the same as those for fatal accidents.

Total Cost of Serious Accidents

In this way the total cost of serious accidents to the coal industry, at current prices, can be calculated as simply the product of number of accidents and the cost per case. Values for these are tabulated in Appendix 7.222c, page 237.

7.223 Minor Accidents

These are all accidents which result in more than three days absence from work and are neither serious nor fatal.

Number of Minor Accidents

Exactly the same method as that used for the two other categories, has been adopted here to derive the number of minor accidents on the longwall mechanised faces. The constant of conversion has been used for accidents caused by Transport and Miscellaneous sources. Constant for transport accidents, assumed to be similar to that of other accidents, i.e. from 0.2 in 1958 to 0.15 in 1980 and that for miscellaneous accidents is taken to be 0.3, which is the mean of constants of conversion of the components of miscellaneous accidents i.e. falling objects, machinery, stumbling, falling and slipping and handling supplies.

Appendix 7.223a shows these values, which have been derived by also using the Health & Safety Executive reports.

Cost per case of Minor Accidents

These accidents may be minor from suffering point of view, but the total cost to the coal industry is far from being negligible. When a man is away from work, the industry effectively has to pay his basic wages, as well as some other costs such as medical attention costs. The injured man, on average, is absent from work 4 - 10 days. The mean for this in 1958 was approximately 5, while in 1980 it was 7.

Total cost per case of minor accidents, the product of which and the total number of these is the total cost of minor accidents, for each year, is tabulated in Appendix 7.223b, page 239.

7.224 Disease Infections

Different mining diseases were described in Section 5.3. Under the Social Security Act claims are allowed to be made for pneumoconiosis, dermatitis, beat hand, knee and elbow, inflammation of wrist and nystagmus. For claims for pneumocomiosis are substantially higher than for other diseases: the financial cost of all other diseases is ignored. To emphasize this point, the coal industry incurred a cost of £13.5 M for pneumocomiosis in 1966.

Number of Pneumoconiosis cases

Statistics only give the number of recognized cases for the whole of the industry. These figures need to be reduced to those attributable to face operations. This is a difficult task, and there can be no entirely satisfactory method. A healthy man, as a result of working in moderately dusty conditions for thirty years, is highly likely to develop pneumocomiosis. A detailed study would have to examine the records of all infected men, which would be too detailed for the purpose of this study and estimation is, once again, resorted to. The proportion of the number of men deployed on the faces to the total number of men working underground can be derived and it is assumed that:

number of pneumocomiosis on the face $\propto$ number of men working on the face. Further, since it is thought that the risk of developing pneumoconiosis is higher for face workers than for others, estimated by approximately 15%, number of pneumoconiosis cases on the face = 1.15 x total number of pneumoconiosis

$$\text{cases} \times \frac{\text{manshifts worked on the faces}}{\text{total underground manshifts worked}}$$

Let number of face manshifts worked be FMS
number of underground manshifts worked be UMS
face output per manshift be FOMS
underground output per manshift be UOMS

$$FOMS = \frac{output}{FMS} \qquad FMS = \frac{output}{FOMS}$$

$$UOMS = \frac{output}{UMS} \qquad UMS = \frac{output}{UOMS}$$

number of pneumocomiosis cases on the face =

$$1.15 \times \text{total number of cases} \times \frac{FMS}{UMS}$$

$$= 1.15 \times \text{total number of cases} \times \frac{UOMS}{FOMS}$$

The two variables UOMS and FOMS are also available in N.C.B. statistics. Normal adjustments i.e. for year definitions and mechanised longwall faces, have been carried out. Values obtained in this way are tabulated in Appendix 7.224a, page 240.

Cost per case of Pneumoconiosis

The following sources have been used to derive data for the cost per case of pneumoconiosis:

(i) Accounts of the N.C.B., Scottish area
(ii) Accounts of the N.U.M., Durham area
(iii) Publications of the Institution of Mining Engineers

Values obtained from different sources were vastly different. Official records only show the direct payments made by the Board, while other sources give substantially higher values, suggesting that compensation is not the only major cost associated with pneumoconiosis. Every attempt, however, has been made to arrive at an estimate, based on the data gathered, which would be of sufficient accuracy. These values are tabulated in Appendix 7.224b, page 240.

Multiplying the two sets of figures calculated in this way, would give the total cost of pneumoconiosis - see Appendix 7.224b.

In this way the total actual cost of accidents is calculated for each year, values of which are tabulated in Appendix 7.225. Using an appropriate price index, viz the general inflation rate, converts the calculated figures to constant prices.

7.23 Testing the Model

Substituting for F, T, s, d and p their actual values obtained in previous chapters, sufficiently good fit is observed. Appendix 7.23 shows the actual and expected safety costs.

7.3 ANALYSIS

7.31 Safety Indicators

Three measures, viz the cost of accidents, output per cost of accidents * (safety cost productivity) and safety costs as a percentage of total inputs cost are examined. Values for these indicators are tabulated in Table 23 and plotted against time in Figure 41.

Year	Total Cost of Accidents index	Safety Cost Productivity tonnes/£	Safety Cost Productivity index	Safety cost per total input %age	Safety cost per total input index
58	100.0	29.0	100.0	2.77	100.0
59	103.0	32.3	111.4	2.48	89.5
60	116.1	31.9	110.0	2.60	93.9
61	125.1	34.8	120.0	2.47	89.2
62	130.1	41.9	144.5	2.16	78.0
63	143.0	48.2	166.2	2.12	76.5
64	158.3	48.5	167.2	2.25	81.2
65	158.2	52.2	180.0	2.11	76.2
66	163.5	51.3	176.9	2.15	77.6
67	148.1	57.0	196.6	2.02	72.9
68	137.3	64.2	221.4	1.87	67.5
69	116.0	72.7	250.7	1.78	64.3
70	89.4	78.8	271.7	1.62	58.5
71	87.1	85.2	293.8	1.49	53.8
72	76.7	79.1	272.8	1.51	54.5
73	75.1	95.4	329.0	1.26	45.5
74	74.4	73.6	253.8	1.45	52.3
75	63.3	101.9	351.4	1.12	40.4
76	71.4	89.2	307.6	1.24	44.8
77	61.9	97.7	336.9	1.10	39.7
78	57.6	103.2	355.9	1.00	36.1
79	61.9	95.1	327.9	1.08	39.0
80	53.6	114 0	393.1	0.92	33.2

Table 23: Analysis of Safety Cost

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* "output per cost of accidents" = $\dfrac{\text{Total saleable output}}{\text{Total cost of accidents}}$

at longwall faces

The values of total safety cost and its graph do not reveal much apart from showing that the general trend is downwards and safety costs have decreased by 46.4% from 1958 to 1980.

Safety cost per total input ratio also shows a decline over most of the period and its level in 1980 was 76.8% less than that of 1958. In 1980 the cost of accidents constituted 0.92% of the total input cost as compared with 2.77% in 1958.

Safety cost productivity values, by showing a 293.1% increase, agree with the above results, leading to the conclusion that from the technological economics point of view coal faces show improvements in safety. The rate of improvement for all the three graphs seems to have slowed down, supporting the earlier argument that safety is now near saturation point and further improvements can be brought about only by a revolutionary technique, method or equipment.

Regarding total productivity, it can be seen that the safety cost component shows the best improvement. Although this constitutes a small percentage of the total input, its effect on improving total productivity is undeniable.

7.32 Safety Cost Components

The actual cost of different categories of accidents were calculated in Section 7.22.

From 1958 - 1980 the following are observed:

Fatal accidents cost	71.1% decrease
Serious accidents cost	2.5% increase
Minor accidents cost	45.0% increase
Pneumoconiosis cost	89.7% decrease

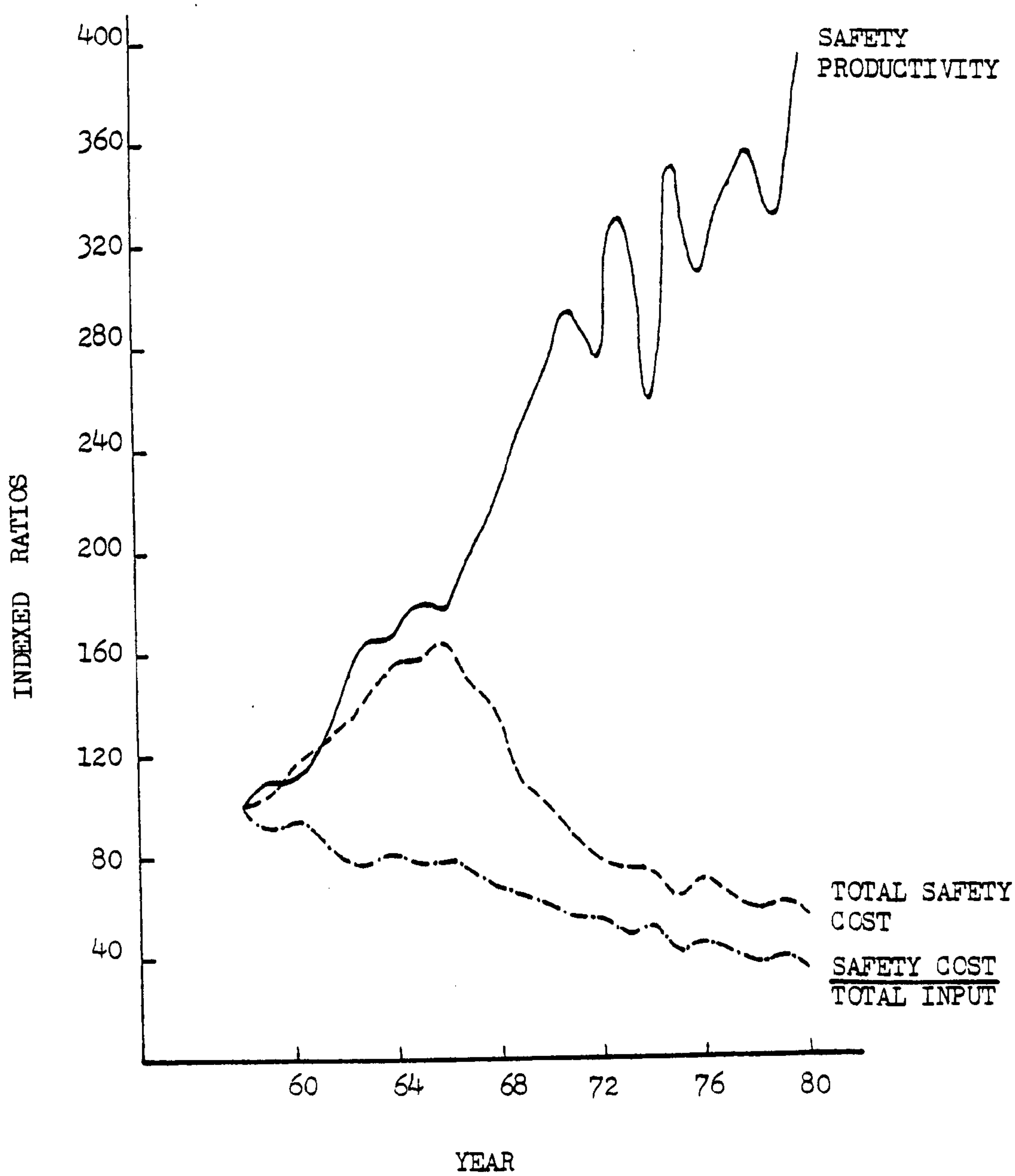

Figure 41 - Analysis of Safety Cost

Table 24 gives the ratio of output to the cost of different categories of accidents. Values in this table actually show the productivity of each category, from which it can be seen that productivity of fatal accidents cost* has risen by seven-fold and that of pneumoconiosis by twenty-fold. Values for the two other categories, on the other hand, do not show much improvement over the years under consideration. Serious accidents productivity, despite a fall in earlier years, shows a gradual increase and in 1980 stands at a level of 106% higher than that in 1958. The mean improvement over the period is 44.8%. Minor accidents productivity, also, does not show much improvement and the mean change is near zero (0.6% increase). However, it shows an increasing trend since the late 1960's and its value in 1980 was 45% higher than in 1958.

The overall conclusion is that safety figures during the period 1958 to 1980 show good improvements but more attempts are required now, in order to reduce the cost of serious reportable and minor accidents.

* "productivity of fatal accidents cost" = $\dfrac{\text{Total saleable output}}{\text{Total cost of fatal accidents at longwall faces.}}$

Year	Output/serious accidents cost index	Output/fatal accidents cost index	Output/minor accidents cost index	Output/ pneumoconiosis cost index
58	100.0	100.0	100.0	100.0
59	92.0	109.4	88.6	133.6
60	89.2	103.6	85.6	137.2
61	92.6	115.9	76.8	177.0
62	90.6	136.9	85.2	267.0
63	96.8	148.5	87.4	411.6
64	105.5	140.5	80.6	490.1
65	107.8	172.7	72.3	946.6
66	120.7	160.0	67.3	1086.4
67	121.2	210.4	73.8	1218.5
68	132.2	225.0	84.7	1416.2
69	163.8	258.9	93.5	1507.8
70	184.9	285.6	99.9	1591.0
71	182.5	312.2	115.3	1380.0
72	175.9	307.6	102.6	1389.8
73	183.4	416.6	124.9	1712.1
74	157.6	304.9	92.9	1525.6
75	207.4	551.8	132.7	1453.2
76	164.3	437.6	119.8	1454.3
77	193.5	432.2	129.4	1650.4
78	177.8	775.0	130.9	1885.5
79	185.3	370.4	124.5	2049.0
80	205.6	728.6	145.1	2043.6

Table 24 Analysis of Safety Cost Components

Table 25 gives the percentage of total safety cost for each category.

Year	Fatal accidents cost/total Safety cost % age	Serious accidents cost/total Safety cost % age	Minor accidents cost/total Safety cost % age	Pneumoconiosis cost/total Safety cost % age
58	15.4	12.6	21.4	50.6
59	15.7	15.2	26.9	42.3
60	16.4	15.5	27.5	40.6
61	16.0	16.3	33.4	34.3
62	16.3	20.1	36.3	27.4
63	17.3	21.6	40.7	20.5
64	18.4	19.9	44.4	17.3
65	16.1	21.0	53.3	9.6
66	17.1	18.4	56.3	8.3
67	14.4	20.4	57.0	8.2
68	15.2	21.0	55.9	7.9
69	14.9	19.3	57.4	8.4
70	14.7	18.5	58.2	8.7
71	14.5	20.2	54.5	10.8
72	13.7	19.5	56.9	9.9
73	12.1	22.4	55.9	9.7
74	12.8	20.3	58.5	8.4
75	9.8	21.3	56.6	12.2
76	10.8	23.5	54.9	10.7
77	12.0	21.9	55.7	10.3
78	7.1	25.2	58.2	9.6
79	13.7	22.3	56.4	8.1
80	8.3	24.0	57.9	9.7

Table 25 Analysis of Safety Cost Components

To reduce fluctuations, the mean value of each four year period is taken and summarized in Table 26.

Period	Fatal Accidents	Serious Accidents	Minor Accidents	Pneumoconiosis
58 - 60	15.8	14.4	25.3	44.5
61 - 64	17.0	19.5	38.7	24.9
65 - 68	15.7	20.2	55.6	8.5
69 - 72	14.5	19.4	56.8	9.5
73 - 76	11.4	21.9	56.5	10.3
77 - 80	10.3	23.4	57.1	9.4

Table 26 Safety Cost Components

Table 26 together with Figure 42 show clearly how total safety cost has been allocated to different categories during the period. The picture is now completely different from that of late 1950's. In 1980 minor and serious accidents costs together constituted 82% of the total safety costs, further emphasizing that any attempt to reduce the cost of safety and consequently to improve safety productivity should be directed towards these.

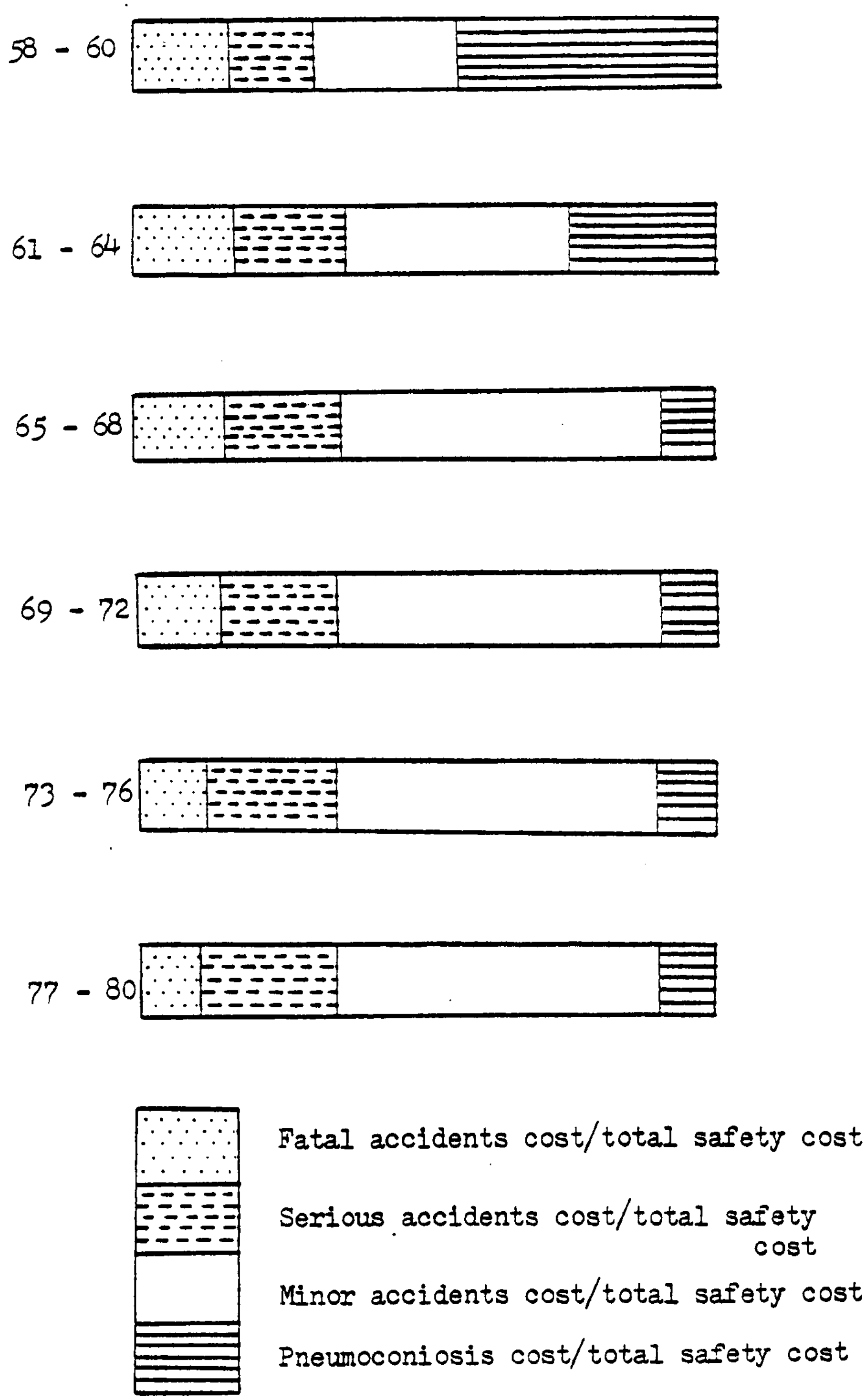

Figure 42 Safety Cost Components

8. RELATIONSHIPS WITH TECHNOLOGICAL CHANGE

8.1 Introduction

From the discussion of technological change earlier (see pages 5 - 15), it seems clear that it is difficult, if not impossible, to define technological change in a general way that is applicable to all industries or productive systems. The best one can hope to do is to select major components of technological change, and investigate how productivity and safety depend on one or more of these components.

For the purposes of the present work, i.e. in relation to mechanised longwall coal faces, the relevent components are considered to be:

T Output per shift (tonnes)

R Mean rate of advance (metres per shift)

$\frac{P}{F}$ Fraction of longwall faces equipped with powered supports
(It is convenient in the model to use as one component exp $(\frac{P}{F})$.)

During a time of reduction of the labour force at the face, it seems reasonable to assume that a change in any one ofthese represents a change in technology of some sort. Although R and T are related, the capital cost model incorporates the product TR.

8.2 TOTAL PRODUCTIVITY

The rate of change of total productivity (T.P.) with respect to technology, or the effect of technological change on total productivity, can be found by partially differentiating model (7) with respect to technology, the indicatives of which in model (7) being T, R and (exp $\frac{P}{F}$).

$$\text{T.P.} = \frac{P}{W + C + S + M + P'} \qquad \text{Model (7)}$$

Rate of change of total productivity with respect to technology is then:

$$\frac{\partial(\text{T.P.})}{\partial(\text{Tech})} = \frac{\partial(\text{T.P.})}{\partial m} = \frac{\partial^3 (\text{T.P.})}{\partial T \quad \partial R \quad \partial(e^{\frac{P}{F}})} \qquad \text{Let } \partial m = \partial(\text{Tech})$$

$$= \frac{\frac{\partial P}{\partial m}(W + C + S + M + P') - P\left(\frac{\partial W}{\partial m} + \frac{\partial C}{\partial m} + \frac{\partial S}{\partial m} + \frac{\partial P'}{\partial m} + \frac{\partial M}{\partial m}\right)}{(W + C + S + M + P')^2}$$

Differentiating models 1 - 6 partially with respect to T, R and $e^{\frac{P}{F}}$ would give $\frac{\partial P}{\partial m}$, $\frac{\partial W}{\partial m}$, $\frac{\partial C}{\partial m}$, $\frac{\partial S}{\partial m}$, $\frac{\partial M}{\partial m}$ and $\frac{\partial P'}{\partial m}$

In this way model (8), which gives the rate of change of total productivity with respect to technology, is constructed.

$$\frac{\partial(\text{T.P.})}{\partial(\text{Technology})} = \frac{\frac{\partial P}{\partial m}(W + C + S + M + P') - P\left(\frac{\partial W}{\partial m} + \frac{\partial C}{\partial m} + \frac{\partial S}{\partial m} + \frac{\partial M}{\partial m} + \frac{\partial P'}{\partial m}\right)}{(W + C + S + M + P')^2} \quad \ldots . \; 8$$

Where P, W, C, S, M and P' are models 1 - 6 of Section 6.33 respectively, and

$$\frac{\partial P}{\partial m} = 0.84 \times 10^{-6} \; F s \; B^{\frac{1}{2}} \; d \qquad \text{......(8.1)}$$

$$\frac{\partial W}{\partial m} = 91.2 \times 10^{-6} \; F^{0.85} \; T^{0.2} \; L^{0.125} \; B^{-2} \; e^{-\frac{1.25p}{F}} \qquad \text{......(8.2)}$$

$$\frac{\partial C}{\partial m} = (25.23 \times 10^{-10} \; FLB^{\frac{1}{2}} \; RP_1^{\;-2} \; T) \; (1.17^{\frac{TR}{23P_1}}) \qquad \text{......(8.3)}$$

$$\frac{\partial S}{\partial m} = 3.33 \times 10^{-7} \; F^{0.8} \; T^{-0.2} \; s \; d \; e^{\frac{-2.2p}{F}} \qquad \text{......(8.4)}$$

$$\frac{\partial M}{\partial m} = 4.495 \times 10^{-5} \; F^{1.3} \; s \; d \; T^{-2} \qquad \text{......(8.5)}$$

$$\frac{\partial P'}{\partial m} = 3.083 \times 10^{-8} \; F^{0.74} \quad T^{0.22} \quad sd \qquad \text{......(8.6)}$$

The function Total Productivity = f (technology) is a four dimensional one, and therefore cannot be plotted easily, but rate of change of productivity with respect to technology, model (8), for which a distinct real number can be calculated in each year, can be plotted. Positive partial derivatives show that the function is increasing while negative ones reflect the fact that the function has a decreasing trend in that particular year.

It must be noted that models 8.1 - 8.6 as well as being components of model 8, are important individually, since they measure the influence of technological change on input components. For example, model 8.2 measures the effects of technological change on the labour cost.

For 1980

$P = 100.5$ $\qquad \frac{\partial P}{\partial m} = +0.323$

$W = 50.49$ $\qquad \frac{\partial W}{\partial m} = -18.42 \times 10^{-3}$

$C = 41.45$ $\qquad \frac{\partial C}{\partial m} = +59.92 \times 10^{-3}$

$S = 0.938$ $\qquad \frac{\partial S}{\partial m} = -10.933 \times 10^{-4}$

$M = 0.315$ $\qquad \frac{\partial M}{\partial m} = -10.018 \times 10^{-4}$

$P' = 1.644$ $\qquad \frac{\partial P'}{\partial m} = +63.88 \times 10^{-4}$

$$\frac{\partial T.P}{\partial m} = +2.89 \times 10^{-3}$$

Models 8 - 8.6 indicate that technological change has always tended to increase output, capital cost and power cost, while it tends to decrease labour cost, safety costs and materials and supplies costs.

Numerical calculations for year 1980 show that in that year technology had these effects:

on the positive side: increased output
decreased labour cost (index of the effect = 100)
decreased safety cost (index = 59)
decreased materials and supplies cost (index = 5)

on the negative side: increased capital cost (index = 100)
increased power cost (index = 11).

On the whole the influence of technological change on productivity in the year 1980 was a benefitial one i.e. technological change tended to improve total productivity in 1980.

8.3 SAFETY

The same line of approach, i.e. partial differentiation of the safety cost model, is taken here to analyse the effect of technological change on safety.

$\dfrac{\partial^2 S}{\partial T \;\; \partial(e^{\frac{p}{F}})}$ would give the rate of change of safety costs with respect to technology.

$$\frac{\partial S}{\partial m} = \frac{\partial^2 S}{\partial T \;\; \partial(e^{\frac{p}{F}})} = 3.33 \times 10^{-7} \;\; F^{0.8} \;\; T^{-0.2} \;\; s\,d\,e^{-\frac{2.2P}{F}} \quad \ldots\ldots (8.4)$$

The negative sign shows that improvements in technology have always resulted in reductions in safety costs. The rate of this reduction is indicated by the value of $\frac{\partial S}{\partial m}$ for each year during the period 1958 - 1980, which are tabulated in Table 27.

Since $\frac{\partial S}{\partial m}$ is always negative, the higher $\left|\frac{\partial S}{\partial m}\right|$ the better, as regards both productivity and safety. This shows an increase from 1958 to 1964 and since then shows a decrease to the extent that in 1980 it was reduced to one eleventh of its level in 1964. This proves analytically the earlier claim about the influence of technological change on safety for it shows that technological change is no longer playing a major part in safety improvements and in order to do so, some radical change is required.

Year Ended March	$\left\lvert \dfrac{\partial^2 S \times 10^3}{\partial T \quad \partial(e^{\frac{P}{F}})} \right\rvert$
58	8.90
59	9.22
60	9.62
61	10.00
62	11.42
63	12.37
64	12.67
65	12.53
66	10.68
67	8.34
68	5.90
69	3.25
70	2.32
71	1.91
72	1.87
73	1.74
74	1.53
75	1.37
76	1.40
77	1.25
78	1.21
79	1.15
80	1.09

Table 27 Effect of Technological Change on Safety

9. CONCLUSIONS

9.1 INFERENCES

Technological change is inevitable in the competitive modern world, as well as being deliberate and continuous. It cannot be measured directly and for this reason, the analyst should concentrate on its effects. Further, no one effect can be claimed to be the most reliable basis for measurement and empirical methods are therefore most appropriate. These should be devised to suit individual situations.

The concept of productivity is often misunderstood and misapplied. Any analysis of productivity must encompass all cost elements, and extreme care must be taken not to fall into the trap of implicitly assuming that input components are separable. When measuring productivity, the important questions should be asked as to why measure it. The most realistic measure of productivity would be one which takes all (monetary) costs into consideration (i.e. total productivity), and is defined and measured according to the particular case in question and particular objectives of quantification.

In the coal mining industry of the U.K., many technological improvements, i.e. mechanization, have taken place, but with respect to management techniques and methods a limited number of improvements can be observed over the period 1958 - 1980. Output per manshift (OMS) has always been used to measure productivity in the U.K. coal mining industry. The innovation of a new method is needed more than at any time in the past. Output per manshift cannot in any way be related to profitability.

Technical productivity concept, being the ratio of actual output to the expected output from available machinery, as well as being revealing itself, can be used to convert OMS values to total productivity values. Technical productivity of longwall coal faces equipped with shearer loaders*, decreased from the value of 6.83% in 1958 to 2.17% in 1980, meaning that as more machinery was acquired, the rate of utilization decreased to the extent that in 1980, the N.C.B. used only 2.17% of the capacity of its longwall faces machinery.

The total productivity model, the percentage of error for which has a mean of 2.94 and standard deviation of 2.18, together with the forecasting technique suggested, can be used to predict the total productivity of longwall mechanized faces for future years. It is expected that it will produce fairly accurate results for 5 - 10 years. The actual values show that total productivity of longwall coal faces increased from 80.22 tonnes per £100 in 1958 to 129.60 tonnes per £100 in 1969, from when it decreased to 104.98 tonnes per £100 in 1980.

During the period 1969 - 1980 the N.C.B. paid more attention to the productivity of elsewhere underground, than they did during the period 1958 - 1969, but still the productivity of this category lags behind that of coal faces. It is therefore equally important now to spend efforts in increasing total productivity of other places underground than the coal faces.

* In 1980, 87.8% of the output of longwall faces was won from faces equipped with shearer loaders.

The figures for total output and total input suggest cost inflexibility of the N.C.B. This is presumably due to the high level of fixed costs.

The analysis of labour cost figures show that the OMS method is becoming increasingly invalid for measuring labour productivity; and that labour cost as a fraction of total cost shows a 58.2% decrease. Labour cost constituted 84.3% of the total cost in 1958 and this decreased to 53.3% in 1980.

Capital cost constituted 11.1% of the total input cost in 1958, but increased to 43.8% in 1980. Capital productivity shows a sharp decrease of 67% over the period 1958 - 1980. This is the main cause for the decrease in the total productivity. Since 1969, the additional expenditure on capital equipment has been more than the resultant savings in the labour cost.

Materials and supplies (cost) productivity shows a sharp increase of 235% and the proportion of this as total input cost shows a decrease of 61.4%. Power cost, on the other hand, show a decrease in productivity by 14.6% and its ratio to the total input cost shows an increase of 53.6%. Materials and supplies cost and power cost together constituted 2.04% of the total input cost in 1980.

The safety cost model is expected to give values of the percentage error which have the mean of 6.97 and standard deviation of 5.92. The forecasting method can again be used to predict future safety costs, although in the case of safety only slight reliability can be expected from any model. Actual safety cost at constant prices decreased by 46.4% over the period 1958 - 1980. Over the same period, safety cost productivity increased by 293.1% and the ratio of safety cost to total input cost decreased by 66.8%. In 1980, longwall faces accidents cost the N.C.B. £4,310,875 which was 0.92% of the total input cost.

Over the period under consideration, fatal accidents cost shows a 71.1% decrease, pneumoconiosis cost shows a 89.7% decrease, while serious accidents cost and minor accidents cost show 2.5% and 45% increase respectively.

In the period 1977 - 1980, 57.1% of the total safety cost was attributed to minor accidents, 23.4% to serious accidents, 10.3% to fatal accidents and 9.4% to pneumoconiosis.

During the period 1958 - 1980, technological change tended to increase output, capital cost and power cost, while it tended to decrease labour cost, safety cost and materials and supplies cost.

Technological change tended to decrease safety cost, though with different rates during the period. This rate increased by 42.4% from 1958 to 1964 and from then decreased dramatically so that its value was 91.4% lower in 1980 than in 1964. Technological change hence has ceased to have a great influence on improving safety.

Despite all the above results, it is noticeable that the N.C.B.'s measure of productivity (OMS) shows an improvement in twenty out of twenty-three years considered here. This makes the author believe that there are political reasons for using OMS.

The analysis in the presentation shows that the productivity of coal faces has been in a poor shape since 1969 and remedial action is required. Any such action must incorporate an increase in the capital productivity (pp 173 - 175).

Further, the total productivity model provides the management with a useful tool for sensitivity analysis and highlights the areas in which more attention is needed. The total productivity model can be used to measure the real productivity of coal faces and the empirical method applied can be used to determine the actual productivity values. Using the actual values calculated and the forecasting method suggested, the total productivity of longwall coal faces can be forecast. On the other hand, using the total productivity model and anticipated values for the variables, a forecast can again be produced for the future values of total productivity.

The analysis of technological change provides management with an idea of the degree of effectiveness of past innovations and helps appraisal of future developments.

9.2 FUTURE WORK

One of the main functions of research is that it opens other roads, and that it lays the foundation, for future research. By reading through this report, the research interest would notice numerous lines along which future research can be carried out.

It was shown earlier that the influence of the technical productivity concept, introduced here, on total productivity has always been great. A sensitivity analysis on the technical productivity model is therefore expected to highlight some important points. Further, the relationship between technical productivity, output per manshift and total productivity was only mentioned here. The exact relationship is to be found and in this context the use of linear formulae is recommended to the future researcher.

Sensitivity analysis of the total productivity model is also another possible future line of research.

Although the total productivity model was tested for individual mines, this was done only superficially as the emphasis was on its application at the national and regional levels. The model is basically applicable to individual mines, but it is expected that with slight modification it will result in values as accurate as those in the case of the whole industry.

This report makes cost/bebefit analysis of safety, believed to be the only reasonable way to quantify safety in the mining industry, an easier task.

The total productivity model was subjected to marginal analysis here with respect to technology only. Differentiating the model with respect to any of the variables would provide the analyst with an indication of the influence of that factor on productivity. Further, sensitivity analysis of the derivatives should give hints as to possible actions in order to manage the effects of various factors.

As regards the relationship between technological change, productivity and safety, the foundation is well laid in this report, but there is enormous potential for future research in this area. Attempts should be made to continue the same line of approach, and to measure technological change by other means in order to allow comparison. In this context using output per manshift values in conjunction with technical productivity is particularly recommended.

Sensitivity analysis of the safety cost model would highlight areas on which more attention is required, and the effect of partially differentiating the model would be similar.

This presentation is mainly concerned with longwall faces. The prospective analyst could modify the models to allow for overhead cost, and further, take the same line of approach to devise models for all mines. Using partial differentiation, he can then measure the influence of overhead cost on productivity and also compare the productivity and safety of different places in coal mines.

Finally, the total productivity model and its components would prove useful tools in any future study of the U.K. coal mining management.

Appendix 6.0 - Notation

B	mean seam thickness of longwall mechanised faces
C	annual face capital cost at constant prices
D	Tonnage of coal lost through disputes
d	mean number of face days worked per year
e	the Napierian number
F	number of longwall mechanised faces
F'	number of longwall mechanised faces equipped with powered supports
g	mean density of coal won from longwall mechanised faces
L	mean length of longwall mechanised faces
M	annual materials and supplies costs at constant prices
P	annual output from longwall mechanised faces
P'	annual power cost at constant prices
P_1	Technical productivity - The ratio of actual output from longwall mechanised faces equipped with shearer loaders to potential output.
p	number of faces equipped with powered supports
Q	$= \frac{T\,R}{P_1}$ is a variable used in modelling process
q	$= 1.17^{\frac{Q-38}{23}}$ is a variable used in the modelling process
R	mean rate of advance of longwall mechanised faces per shift
S	annual safety cost at constant prices
s	mean number of face shifts worked per day
s'	mean number of shearer loaders employed at each face
T	mean tonnage of coal extracted per shift per face
V	vend (the ratio of saleable tonnage to pit head tonnage)
v	mean effective speed of shearer loaders
W	annual face labour cost at constant prices
w	mean web (depth of cut for shearer loaders)

Appendix 6.21

Year Ended March	Total Deep Mined Saleable Output (M tonnes)	% of Mechanised Output as per Total Output	% of Long-wall Output as per Total Mechanised Output	% of Output from Shearer-loader Faces as per Total Mechanised Output	Actual Output from Shearer-Loader Faces (M tonnes)
1958	208.5	24.2	94.3	39.0	18.6
1959	200.4	28.7	95.1	38.5	21.1
1960	193.4	32.9	95.6	38.6	23.5
1961	185.7	40.1	95.9	37.1	26.5
1962	184.5	50.5	96.1	39.1	35.0
1963	191.5	61.2	96.6	46.6	52.8
1964	190.2	68.4	96.9	47.9	60.4
1965	186.6	75.0	96.9	50.3	68.2
1966	176.9	80.7	96.5	50.9	70.1
1967	167.2	85.7	96.8	53.6	74.3
1968	165.3	89.7	97.5	56.5	81.7
1969	155.5	91.8	97.0	63.2	87.5
1970	142.0	92.3	97.2	64.6	82.3
1971	135.4	92.2	97.6	68.3	83.2
1972	111.0	92.2	97.3	72.0	71.7
1973	129.0	93.0	97.3	76.3	89.1
1974	98.7	93.5	97.4	77.3	69.5
1975	116.8	93.5	97.1	77.7	82.4
1976	114.4	93.6	97.6	80.3	83.9
1977	108.4	93.8	97.8	81.5	81.0
1978	106.2	93.6	98.1	83.0	80.9
1979	105.4	93.5	98.0	84.7	81.8
1980	109.3	93.6	98.0	86.7	86.7

Appendix 6.22

Year Ended March	F	% age of Output from Shearers Faces per Output from Longwall Faces	F'	B (m)	g ($\frac{\text{Tonnes}}{m^3}$)	V	W (m)	s'	v (m/s)	Potential Output (m Tonnes)
1958	763	36.1	270	1.25	1.48	1.82	0.52	1.246	0.029	272.4
1959	895	36.6	321	1.29	1.48	0.82	0.59	1.230	0.032	368.0
1960	988	36.9	358	1.27	1.48	0.82	0.61	1.281	0.037	503.1
1961	1,090	35.6	381	1.27	1.49	0.81	0.62	1.319	0.037	557.2
1962	1,312	37.6	484	1.28	1.49	0.81	0.62	1.332	0.052	1,012.6
1963	1,388	45.0	613	1.30	1.49	0.81	0.62	1.330	0.054	1,350.6
1964	1,427	46.4	650	1.30	1.49	0.81	0.62	1.350	0.054	1,453.6
1965	1,462	48.7	698	1.28	1.49	0.81	0.68	1.378	0.055	1,725.5
1966	1,441	49.1	694	1.25	1.49	0.81	0.69	1.364	0.056	1,740.2
1967	1,407	51.9	716	1.30	1.49	0.81	0.69	1.379	0.064	2,157.4
1968	1,369	55.1	740	1.31	1.49	0.81	0.71	1.393	0.064	2,335.4
1969	1,025	61.3	616	1.33	1.48	0.82	0.72	1.387	0.068	2,129.3
1970	898	62.8	553	1.35	1.48	0.82	0.72	1.407	0.078	2,257.7
1971	849	66.7	556	1.36	1.48	0.82	0.72	1.418	0.078	2,304.6
1972	840	70.1	578	1.37	1.48	0.82	0.72	1.416	0.080	2,471.8
1973	831	74.2	605	1.38	1.48	0.82	0.73	1.410	0.080	2,631.1
1974	778	75.3	575	1.41	1.47	0.83	0.72	1.438	0.082	2,648.5
1975	745	75.4	563	1.42	1.47	0.83	0.74	1.452	0.095	3,139.9
1976	754	78.4	575	1.43	1.47	0.83	0.76	1.444	0.095	3,298.5
1977	720	79.4	563	1.45	1.48	0.82	0.76	1.506	0.101	3,611.8
1978	709	81.4	566	1.46	1.48	0.82	0.77	1.534	0.101	3,773.0
1979	673	83.0	548	1.48	1.48	0.82	0.79	1.532	0.101	3,794.3
1980	649	85.0	539	1.49	1.49	0.82	0.82	1.559	0.102	4,007.9

See Appendix 6.0 for notation

Appendix 6.23

Year Ended March	P_1 Technical Productivity (%)
1958	6.83
1959	5.73
1960	4.67
1961	4.76
1962	3.46
1963	3.91
1964	4.16
1965	3.95
1966	4.03
1967	3.44
1968	3.50
1969	4.11
1970	3.65
1971	3.61
1972	2.90
1973	3.39
1974	2.62
1975	2.62
1976	2.54
1977	2.24
1978	2.14
1979	2.16
1980	2.17

Appendix 6.311

Model (1)

Year Ended March	F	T (Tonnes)	B (m)	D (m Tonnes)	s	Output Per Day per Face (Tonnes)	d	Total Predicted Output from Model 1 (m Tonnes)	Total Actual Output (m Tonnes)	% age Error
1958	747	173	1.28	1.7	1.41	236	274	47.5	47.6	0.21
1959	895	177	1.29	1.4	1.42	244	257	53.8	54.7	1.67
1960	988	181	1.27	1.2	1.45	256	251	60.4	60.8	0.66
1961	1,090	182	1.27	1.7	1.51	268	250	69.2	71.4	3.18
1962	1,312	187	1.28	1.8	1.62	301	241	89.2	89.5	0.34
1963	1,388	199	1.30	1.1	1.75	345	242	110.9	113.2	2.07
1964	1,427	205	1.30	1.4	1.81	366	244	122.3	126.1	3.11
1965	1,462	207	1.28	1.3	1.89	381	246	132.4	135.6	2.42
1966	1,441	208	1.25	1.2	2.02	403	243	137.0	137.8	0.58
1967	1,407	210	1.30	1.7	2.08	435	239	139.0	138.7	-0.22
1968	1,369	222	1.31	0.4	2.19	477	227	144.9	144.6	-0.21
1969	1,025	264	1.33	0.3	2.17	562	241	136.8	138.5	1.24
1970	898	282	1.35	2.9	2.16	602	242	126.3	127.4	0.87
1971	849	293	1.36	3.1	2.08	608	244	120.6	121.8	1.00
1972	840	292	1.37	26.7	2.09	605	249	98.8	99.6	0.81
1973	831	287	1.38	0.6	2.06	587	243	117.2	116.7	-0.43
1974	778	292	1.41	21.3	2.03	591	242	90.0	89.9	-0.11
1975	745	290	1.42	0.4	2.04	590	241	105.9	106.0	0.09
1976	754	287	1.43	0.5	2.05	588	235	104.2	104.5	0.29
1977	720	283	1.45	1.1	2.04	578	239	99.4	99.4	0
1978	709	291	1.46	0.8	2.04	591	233	98.7	97.5	-1.22
1979	673	302	1.48	1.5	2.08	637	229	97.4	96.6	-0.82
1980	649	314	1.49	0.9	2.11	673	230	100.5	100.3	-2.20

See Appendix 6.0 for notation

Appendix 6.3212

Year Ended March	Mechanised Longwall Output (M Tonnes)	Face OMS (Tonnes)	Wage per Shift of Face Workers (£)	Price Index	Actual Face Labour Cost At Constant Prices (£m)
1958	47.6	3.64	3.8220	100.0	49.98
1959	54.7	3.72	4.0108	103.4	57.50
1960	60.8	3.87	4.1667	106.1	61.70
1961	71.4	4.09	4.3125	109.2	68.94
1962	89.5	4.34	4.4833	113.7	81.31
1963	113.2	4.72	4.5222	118.8	91.29
1964	126.1	5.03	4.6600	123.4	94.67
1965	135.6	5.26	4.9958	128.0	100.62
1966	137.8	5.57	5.3577	132.2	100.3
1967	138.2	5.78	5.4127	139.9	92.84
1968	144.6	6.06	5.5112	146.9	89.52
1969	138.5	6.71	5.9042	153.1	79.60
1970	127.4	6.99	6.4892	164.1	72.07
1971	121.8	7.21	7.1971	181.2	67.10
1972	99.6	7.05	7.8532	208.3	53.26
1973	116.7	7.56	9.6916	230.1	65.04
1974	89.9	7.30	10.9388	267.6	50.34
1975	106.0	7.89	13.5139	320.3	56.68
1976	104.5	7.89	16.7144	395.3	56.00
1977	99.4	7.75	18.1570	453.9	51.31
1978	97.5	7.91	21.1510	506.0	51.52
1979	96.6	8.53	25.9810	581.3	50.62
1980	100.3	8.88	30.4220	675.2	50.89

Appendix 6.3213

Model (2)

Year Ended March	F	T (Tonnes)	L (m)	B (m)	P	W Predicted Labour Cost from Model 2 (£M)	Actual Labour Cost (£M)	% age Error
1958	774	173	146	1.28	19	47.58	49.98	5.04
1959	895	177	149	1.29	30	54.49	57.50	5.52
1960	988	181	153	1.27	46	62.81	61.70	- 1.77
1961	1,090	182	157	1.27	87	68.39	68.94	0.80
1962	1,312	187	159	1.28	132	81.13	81.31	0.22
1963	1,388	199	171	1.30	161	89.37	91.29	2.15
1964	1,427	205	178	1.30	188	94.92	94.67	- 0.26
1965	1,462	207	180	1.28	246	100.34	100.62	0.28
1966	1,441	208	175	1.25	374	101.81	100.30	- 1.48
1967	1,407	210	167	1.30	518	90.27	92.84	2.85
1968	1,369	222	167	1.31	699	89.60	89.52	- 0.09
1969	1,025	264	167	1.33	701	80.13	79.60	- 0.66
1970	898	282	170	1.35	703	73.55	72.07	- 2.01
1971	849	293	170	1.36	708	71.43	67.10	- 6.06
1972	840	292	171	1.37	714	69.24	53.26	-23.08
1973	831	287	172	1.38	718	66.05	65.04	- 1.53
1974	778	292	175	1.41	692	60.82	50.34	-17.23
1975	745	290	177	1.42	688	56.92	56.68	- 0.42
1976	754	287	178	1.43	687	56.21	56.00	- 0.37
1977	720	283	180	1.45	686	51.22	51.31	0.18
1978	709	291	181	1.46	672	51.66	51.52	- 0.27
1979	673	302	185	1.48	638	50.42	50.62	0.40
1980	649	314	189	1.49	625	50.49	50.89	0.79

See Appendix 6.0 for notation

Appendix 6.3222

Year Ended March	Cost of Machinery on Each Face with Powered Supports at Current Prices (£)	P	Cost of Machinery on Each Face Without Powered Supports at Current Prices (£)	(F - P)	Total Actual Capital Cost at Current Prices (£)	Price Index	Actual Face Capital Cost at Constant Prices (£m)
1958	42,726	19	34,200	755	6.56	100.0	6.56
1959	50,258	30	35,721	865	7.98	102.2	7.81
1960	62,553	46	36,124	942	9.08	103.1	8.81
1961	81,027	87	36,632	1,003	10.78	105.1	10.26
1962	82,912	132	38,791	1,180	13.96	107.2	13.02
1963	83,929	161	40,784	1,227	15.64	108.5	14.41
1964	89,873	188	41,826	1,239	16.91	109.8	15.41
1965	98,263	246	42,592	1,216	18.70	112.0	16.70
1966	107,500	374	43,814	1,067	21.40	114.7	18.66
1967	123,420	518	46,829	889	25.98	117.2	22.17
1968	131,730	699	47,643	670	30.52	119.4	25.56
1969	138,223	701	49,083	324	27.77	123.8	22.43
1970	159,830	703	52,745	195	30.19	128.8	23.44
1971	189,323	708	55,599	141	33.18	139.0	25.13
1972	219,096	714	61,323	126	40.41	151.6	26.66
1973	260,200	718	63,269	113	47.75	161.4	29.58
1974	320,500	692	68,722	86	56.05	181.4	30.90
1975	432,871	688	80,280	57	74.43	225.8	32.96
1976	565,000	687	101,778	67	97.22	275.1	35.34
1977	715,238	686	113,326	34	121.72	322.5	37.74
1978	904,118	672	136,889	37	150.80	372.9	40.44
1979	1,063,300	638	146,800	35	168.25	412.1	40.83
1980	1,280,200	625	166,900	24	197.94	473.3	41.32

Appendix 6.3223

Model (3)

Year Ended March	T (Tonnes)	R (m)	P_1 (%)	Q (Tonne m)	ρ	F	L (m)	P	B (m)	Predicted Capital Cost from Model 3 (£M)	Actual Face Capital Cost (£M)	% age Error
1958	173	0.82	6.83	20.770	0.889	774	146	19	1.28	6.31	6.56	3.96
1959	177	0.81	5.73	25.021	0.915	895	149	30	1.29	7.76	7.81	0.64
1960	181	0.81	4.67	31.394	0.956	988	153	46	1.27	9.24	8.81	- 4.65
1961	182	0.80	4.76	30.588	0.951	1,090	157	87	1.27	10.75	10.26	- 4.56
1962	187	0.79	3.46	33.123	0.967	1,312	159	132	1.28	14.13	13.02	- 7.86
1963	199	0.80	3.91	40.716	1.019	1,388	171	161	1.30	16.77	14.41	-14.07
1964	205	0.79	4.16	38.930	1.006	1,427	178	188	1.30	17.99	15.41	-14.34
1965	207	0.78	3.95	40.876	1.020	1,462	180	246	1.28	19.45	16.70	-14.14
1966	208	0.79	4.03	40.774	1.019	1,441	175	374	1.25	20.16	18.66	- 7.44
1967	210	0.77	3.44	47.006	1.063	1,407	167	518	1.30	22.28	22.17	- 0.49
1968	222	0.83	3.50	52.646	1.105	1,369	167	699	1.31	26.08	25.56	- 1.99
1969	264	0.95	4.11	61.022	1.170	1,025	167	701	1.33	24.78	22.43	- 9.48
1970	282	1.00	3.65	77.260	1.307	898	170	703	1.35	27.46	23.44	-14.64
1971	293	1.02	3.61	82.787	1.358	849	170	708	1.36	28.49	25.13	-11.79
1972	292	1.01	2.90	101.692	1.545	840	171	714	1.37	32.90	26.66	-18.97
1973	287	0.99	3.39	83.814	1.367	831	172	718	1.38	29.48	29.58	0.34
1974	292	0.98	2.62	109.221	1.626	778	175	692	1.41	34.64	30.90	-10.80
1975	290	0.95	2.62	105.153	1.582	745	177	688	1.42	33.89	32.96	- 2.74
1976	282	0.95	2.54	107.343	1.605	754	178	687	1.43	34.69	35.34	1.87
1977	283	0.89	2.24	112.442	1.662	720	180	686	1.45	36.41	37.74	3.65
1978	291	0.92	2.14	125.103	1.812	709	181	672	1.46	39.25	40.44	3.03
1979	302	0.94	2.16	131.426	1.892	673	185	638	1.48	40.04	40.83	1.97
1980	314	0.94	2.17	136.018	1.952	649	189	625	1.49	41.45	41.82	0.89

See Appendix 6.0 for notation

Appendix 6.3242

Year Ended March	Materials & Supplies Cost per Tonne of Coal at Current Prices (£)	Actual Output (M Tonnes)	Total Actual Materials & Supplies Cost at Current Prices (£M)	Price Index	Actual Materials & Supplies Cost at Constant Prices (£M)
1958	0.0103	47.6	0.4918	100.0	0.491
1959	0.0110	54.7	0.6007	100.3	0.599
1960	0.0116	60.8	0.7082	102.2	0.693
1961	0.0125	71.4	0.8957	106.0	0.845
1962	0.0127	89.5	1.1366	110.6	1.028
1963	0.0117	113.2	1.3290	113.3	1.173
1964	0.0111	126.1	1.4028	116.8	1.201
1965	0.0113	135.6	1.5325	122.7	1.249
1966	0.0113	137.8	1.5592	127.8	1.220
1967	0.0104	138.7	1.4397	131.6	1.094
1968	0.0099	144.6	1.4417	137.3	1.050
1969	0.0086	138.5	1.1855	144.4	0.821
1970	0.0073	127.4	0.9275	152.8	0.607
1971	0.0078	121.8	0.9533	165.5	0.576
1972	0.0077	99.6	0.7669	177.1	0.433
1973	0.0071	116.7	0.8309	189.7	0.438
1974	0.0079	89.9	0.7077	215.1	0.329
1975	0.0103	106.0	1.0918	261.3	0.418
1976	0.0127	104.5	1.3272	307.5	0.432
1977	0.0148	99.4	1.4714	353.7	0.416
1978	0.0149	97.5	1.4521	389.3	0.373
1979	0.0155	96.6	1.4956	438.6	0.341
1980	0.0160	100.3	1.6028	518.7	0.309

Appendix 6.3243

Model (5)

Year Ended March	F	T (Tonnes)	d	s	Predicted Materials & Supplies Cost at Constant Prices from Model (£M)	Actual Materials & Supplies Cost at Constant Prices (£M)	% age Error
1958	774	173	274	1.41	0.572	0.491	-14.16
1959	895	177	257	1.42	0.637	0.599	- 5.97
1960	988	181	251	1.45	0.707	0.693	- 1.98
1961	1,090	182	250	1.51	0.828	0.845	2.05
1962	1,312	187	241	1.62	1.061	1.028	- 3.11
1963	1,388	199	242	1.75	1.164	1.173	0.77
1964	1,427	205	244	1.81	1.221	1.201	- 1.64
1965	1,462	207	246	1.89	1.314	1.248	- 4.95
1966	1,441	208	243	2.02	1.355	1.220	- 9.96
1967	1,407	210	239	2.08	1.318	1.094	-17.00
1968	1,369	222	227	2.19	1.203	1.050	-12.72
1969	1,025	264	241	2.17	0.730	0.821	12.47
1970	898	282	242	2.16	0.575	0.607	5.57
1971	849	293	244	2.08	0.500	0.576	15.2
1972	840	292	249	2.09	0.507	0.433	-14.60
1973	831	287	243	2.06	0.490	0.438	-10.61
1974	778	292	242	2.03	0.433	0.329	-24.02
1975	745	290	241	2.04	0.413	0.418	1.21
1976	754	287	235	2.05	0.415	0.432	4.10
1977	720	283	239	2.04	0.401	0.416	3.74
1978	709	291	233	2.04	0.373	0.373	0
1979	673	302	229	2.08	0.337	0.341	1.19
1980	649	314	230	2.11	0.315	0.309	- 1.90

See Appendix 6 for notation

Appendix 6.3252

Year Ended March	Cost of Elec Energy/Tonne of Coal at Current Prices (£)	Longwall Mechanised Output (M Tonnes)	Face Actual Power Cost at Current Prices (£M)	Price Index	Actual Power Cost at Constant Prices (£M)
1958	0.014	47.6	0.666	100.0	0.666
1959	0.013	54.7	0.711	100.3	0.709
1960	0.013	60.8	0.790	102.2	0.773
1961	0.014	71.4	1.000	106.0	0.943
1962	0.015	89.5	1.343	110.6	1.214
1963	0.015	113.2	1.698	113.3	1.500
1964	0.016	126.1	2.018	116.8	1.727
1965	0.017	135.6	2.305	122.7	1.879
1966	0.018	137.8	2.480	127.8	1.941
1967	0.018	138.7	2.500	131.6	1.897
1968	0.020	144.6	2.892	137.3	2.106
1969	0.022	138.5	3.047	144.4	2.110
1970	0.023	127.4	2.930	152.8	1.918
1971	0.025	121.8	3.045	165.5	1.840
1972	0.027	99.6	2.690	177.1	1.518
1973	0.029	116.7	3.384	189.7	1.784
1974	0.034	89.9	3.057	215.1	1.421
1975	0.040	106.0	4.240	261.3	1.623
1976	0.048	104.5	5.016	307.5	1.631
1977	0.056	99.4	5.566	353.7	1.574
1978	0.063	97.5	6.143	389.3	1.578
1979	0.072	96.6	6.955	438.6	1.586
1980	0.085	100.3	8.526	518.7	1.644

Appendix 6.3253 Model (6)

Year Ended March	T (Tonnes)	F	s	d	P′ Predicted Power Cost From Model 6 (£M)	Actual Power Cost (£M)	% age Error
1958	173	774	1.41	274	0.720	0.666	- 7.50
1959	177	895	1.42	257	0.779	0.709	- 8.99
1960	181	988	1.45	251	0.859	0.773	-10.01
1961	182	1,090	1.51	250	0.965	0.943	- 2.28
1962	187	1,312	1.62	241	1.183	1.214	2.62
1963	199	1,388	1.75	242	1.443	1.500	3.95
1964	205	1,427	1.81	244	1.593	1.727	8.41
1965	207	1,462	1.89	246	1.728	1.879	8.74
1966	208	1,441	2.02	243	1.815	1.941	6.94
1967	210	1,407	2.08	239	1.828	1.897	3.77
1968	222	1,369	2.19	227	1.917	2.106	9.86
1969	264	1,025	2.17	241	2.011	2.110	4.92
1970	282	898	2.16	242	1.975	1.918	- 2.89
1971	293	849	2.08	244	1.927	1.840	- 4.51
1972	292	840	2.09	249	1.953	1.518	-22.27
1973	287	831	2.06	243	1.825	1.784	- 2.25
1974	292	778	2.03	242	1.742	1.421	-18.43
1975	290	745	2.04	241	1.674	1.623	- 3.05
1976	287	754	2.05	235	1.634	1.631	- 0.18
1977	283	720	2.04	239	1.571	1.574	0.19
1978	291	709	2.04	233	1.567	1.578	0.70
1979	302	673	2.08	229	1.581	1.586	0.32
1980	314	649	2.11	230	1.644	1.644	0

See Appendix 6 for notation

Appendix 6.33a

TOTAL PRODUCTIVITY COMPONENTS FROM MODELS

Year Ended March	P 1	W 2	C 3	S 4	M 5	P′ 6	Total Productivity (Tonnes per £100) From Model 7
1958	47.5	47.58	6.31	1.644	0.572	0.720	83.59
1959	53.8	54.49	7.76	1.758	0.637	0.779	82.23
1960	60.4	62.81	9.24	1.902	0.707	0.859	79.98
1961	69.2	68.39	10.75	2.057	0.828	0.965	83.38
1962	89.2	81.13	14.13	2.461	1.061	1.183	89.23
1963	110.9	89.57	16.77	2.879	1.164	1.443	99.35
1964	122.3	94.92	17.99	3.089	1.221	1.593	102.93
1965	132.4	100.34	19.45	3.197	1.314	1.728	105.06
1966	137.0	101.81	20.16	3.000	1.355	1.815	106.91
1967	139.0	90.27	22.28	2.639	1.318	1.828	117.46
1968	144.9	89.60	26.08	2.275	1.203	1.917	119.68
1969	136.8	80.13	24.78	1.775	0.730	2.011	125.02
1970	127.3	73.55	27.46	1.491	0.575	1.975	120.23
1971	120.6	71.43	29.48	1.340	0.500	1.927	116.31
1972	98.8	69.24	32.90	1.333	0.507	1.953	93.27
1973	117.2	66.05	29.48	1.233	0.490	1.825	118.29
1974	90.0	60.82	34.64	1.130	0.433	1.742	91.13
1975	105.9	56.92	33.89	1.043	0.413	1.674	112.73
1976	104.2	56.21	34.69	1.038	0.415	1.634	110.87
1977	99.4	51.22	36.41	0.954	0.401	1.571	109.77
1978	98.7	51.66	39.25	0.945	0.373	1.567	105.23
1979	97.4	50.42	40.04	0.936	0.337	1.581	104.38
1980	100.5	50.49	41.45	0.938	0.315	1.644	105.97

See Appendix 6.0 for notation

Appendix 6.33b

TOTAL PRODUCTIVITY ACTUAL COMPONENTS

Year Ended March	Output (M Tonnes)	Labour Cost (£M)	Capital Cost (£M)	Safety Cost (£M)	Materials & Supplies Cost (£M)	Power Cost (£M)	Actual Total Productivity (Tonnes per £100)
1958	47.6	49.98	6.56	1.642	0.491	0.666	80.22
1959	54.7	52.50	7.81	1.692	0.599	0.709	80.08
1960	60.8	61.70	8.81	1.906	0.693	0.773	82.29
1961	71.4	68.94	10.26	2.052	0.845	0.943	85.98
1962	89.5	81.31	13.02	2.137	1.028	1.214	90.67
1963	113.2	91.29	14.41	2.348	1.173	1.500	102.24
1964	126.1	94.67	15.41	2.599	1.201	1.727	109.08
1965	135.6	100.62	16.70	2.598	1.249	1.879	110.20
1966	137.8	100.30	18.66	2.684	1.220	1.941	110.41
1967	138.2	92.84	22.17	2.432	1.094	1.897	115.17
1968	144.6	89.52	25.56	2.254	1.050	2.106	120.01
1969	138.5	79.60	22.43	1.904	0.821	2.110	129.60
1970	127.4	72.07	23.44	1.616	0.607	1.918	127.85
1971	121.8	67.10	25.13	1.430	0.576	1.840	126.77
1972	99.6	53.26	26.66	1.259	0.433	1.518	119.81
1973	116.7	65.04	29.58	1.233	0.438	1.784	118.99
1974	89.9	50.34	30.90	1.221	0.329	1.421	106.76
1975	106.0	56.68	32.96	1.040	0.418	1.623	114.32
1976	104.5	56.00	35.34	1.172	0.432	1.631	110.49
1977	99.4	51.31	37.74	1.017	0.416	1.574	107.98
1978	97.5	51.52	40.44	0.945	0.373	1.578	102.79
1979	96.6	50.62	40.83	1.016	0.341	1.586	102.34
1980	100.3	50.89	41.82	0.880	0.309	1.644	104.98

Appendix 6.33c

Year Ended March	Actual Total Productivity	Predicted Total Productivity From Model (7)	%age Error
1958	80.22	83.59	- 4.03
1959	80.08	82.23	- 2.61
1960	82.29	79.78	2.89
1961	85.98	83.38	3.12
1962	90.67	89.23	1.61
1963	102.24	99.35	2.91
1964	109.08	102.93	5.97
1965	110.20	105.06	4.89
1966	110.41	106.91	3.27
1967	115.17	117.46	- 1.95
1968	120.01	119.68	0.28
1969	129.60	125.02	3.66
1970	127.85	120.23	6.34
1971	126.77	116.31	8.99
1972	119.81	93.27	28.46
1973	118.99	118.29	0.59
1974	106.76	91.13	17.15
1975	114.32	112.73	1.41
1976	110.49	110.87	- 0.34
1977	107.98	109.77	- 1.63
1978	102.79	105.23	- 2.32
1979	102.34	104.38	- 1.95
1980	104.98	105.97	- 0.93

Appendix 6.332

1	t	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76		77	78	79	80
2	n_t	80.22	80.08	82.29	85.98	90.67	102.24	109.8	111.20	110.41	115.17	120.01	129.60	127.85	126.77	119.81	118.99	106.76	114.32	110.49	107.98	107.98	102.79	102.34	104.98
3	n_t		80.08	79.94	83.40	88.69	94.69	110.46	117.32	114.53	111.64	117.98	124.25	136.88	130.88		126.72		114.45	108.92	105.91	105.91	104.62	98.71	100.02
4	$n_t - n_t$		0	2.35	2.58	1.98	7.55	- 1.38	- 7.12	- 4.12	3.53	2.03	5.35	- 9.03	- 4.11		- 7.73		- .13	1.57		2.07	- 1.83	3.63	
5	$0.9\ (n_t - n_t)$		0	2.115	2.322	1.782	6.79	- 1.240	- 6.410	- 3.708	3.177	1.827	4.815	- 8.127	- 3.7		- 6.952		- .117	1.413		1.863	- 1.65	3.267	
6	m_t 3 + 5	80.22	80.08	82.060	85.722	90.47	101.48	109.220	110.910	110.700	114.820	119.810	129.060	128.750	127.181		119.770		114.33	110.33		107.77	102.97	102	
7	$m_t - m_{t-1} = r_t$		- .14	1.975	3.667	4.75	11.013	7.733	1.694	- .21	4.115	4.99	9.258	- .312	- 1.572		- 7.408		- 5.44	- 4		- 2.56	- 4.76	- .996	
8	r_t		- .14	- .14	1.341	2.969	4.216	8.974	8.105	3.617	0.938	3.162	4.442	7:813	2.1255		- .463		- 5.325	- 5.401		- 4.418	- 3.117	- 4.267	
9	$r_t - r_t$		0	2.115	2.326	1.781	6.797	- 1.241	- 6.411	- 3.827	3.117	1.828	4.816	- 8.125	- 3.698		- 6.945		- .115	1.404		1.858	- 1.643	3.271	
10	$0.7\ (r_t - r_t)$		0	1.481	1.628	2.6467	4.758	- .869	- 4.488	- 2.679	2.224	1.28	3.371	- 5.688	- 2.588		- 4.862		- .081	.983		1.301	- 1.15	2.29	
11	r_{t+1} 8 + 10		- .14	1.3405	2.969	4.216	8.974	8.105	3.617	.938	3.162	4.4416	7.813	2.1255	- .463		- 5.325		- 5.401	- 4.418		- 3.117	- 4.267	- 1.977	
12	n_{t+1} 6 + 11		79.94	83.40	88.691	94.69	110.46	117.32	114.53	111.64	117.98	124.25	136.88	130.88	126.72		114.45		108.92	105.91		104.62	98.71	100.02	
	% age error			2.94	3.09	2.23	7.97	- 1.25	- 6.07	- 3.6	3.16	1.72	4.32	- 6.6	- 3.14		- 6.1		- .11	1.44	-	1.95	- 1.75	3.68	4.96

Appendix 7.221a

Year Ended March	Number of Face Fatal Accidents (i)	Total No. of Accidents (Fatal) (ii)	Constant for Conversion (ii)	Face Fatal Accidents (ii)	Total No. Fatal Accidents (iii)	Constant for Conversion (iii)	Face Fatal Accidents (iii)	Total Fatal Accidents (iv)	Constant for Conversion (iv)	Face Fatal Accidents (iv)	Percentage of Mechanised Longwall Output per Total Output	Total No. of longwall Mechanised Faces Facilities
1958	149	93	0.2	19	15	0.80	12	77	0.20	15	22.8	44
1959	131	82	0.2	16	10	0.80	8	60	0.20	12	27.3	46
1960	125	73	0.2	15	13	0.80	10	93	0.20	19	31.5	53
1961	105	66	0.19	13	13	0.80	10	68	0.21	14	38.5	55
1962	90	62	0.19	12	12	0.79	9	38	0.21	8	48.5	58
1963	82	76	0.19	14	12	0.79	9	49	0.21	10	59.1	68
1964	95	69	0.19	13	8	0.79	6	26	0.22	6	66.3	80
1965	70	62	0.18	11	9	0.79	7	32	0.22	7	72.7	69
1966	66	50	0.18	9	14	0.78	11	44	0.22	10	77.9	75
1967	52	60	0.18	11	3	0.78	2	19	0.23	4	83.0	57
1968	44	38	0.18	7	8	0.78	6	26	0.23	6	87.5	55
1969	32	32	0.18	6	10	0.78	8	20	0.23	5	89.0	45
1970	25	34	0.17	6	10	0.77	8	10	0.24	2	89.7	37
1971	23	38	0.17	6	5	0.77	4	11	0.24	3	90.0	32
1972	19	22	0.17	4	4	0.77	3	14	0.24	3	89.7	26
1973	14	23	(0.13)	3	3	(1.00)	3	17	0.25	4	90.5	22
1974	14	17	(0.06)	1	4	(0.75)	3	26	0.25	7	91.1	23
1975	9	14	(0.14)	2	6	(0.67)	4	8	0.25	2	90.8	15
1976	9	15	(0.33)	5	6	(0.50)	3	12	0.25	3	91.4	18
1977	11	14	(0.07)	1	5	(1.00)	5	5	0.25	1	91.7	17
1978	6	25	(0.04)	1	3	(0.67)	2	5	0.25	1	91.8	9
1979	9	24	0.15	3	5	0.75	4	15	0.25	4	91.6	18
1980	6	11	0.15	2	3	0.75	2	5	0.25	1	91.7	10

Appendix 7.221b

Year Ended March	Common Law Damage & Compensation Costs Per Case (i) (£)	No. of Un-Productive Shifts (ii)	Wage Per Shift (ii) (£)	Replace-ment Cost per Case (ii) (£)	Other Costs Per Case (iii) (£)	Total Cost of Fatal Accidents Per Case (£)
1958	5,346	59	3.4398	202.95	203	5,751.95
1959	5,496	59	3.6097	212.97	204	5,912.97
1960	5,630	61	3.7500	228.75	210	6,068.75
1961	5,794	60	3.8813	232.88	212	6,238.88
1962	6,045	60	4.0350	242.10	215	6,502.10
1963	6,239	61	4.0700	248.27	219	6,706.27
1964	6,391	61	4.1940	255.83	224	6,870.83
1965	6,721	62	4.4962	278.76	223	7,222.76
1966	7,088	62	4.8219	298.96	234	7,620.96
1967	7,404	63	4.8714	306.90	241	7,951.90
1968	7,725	62	4.9601	307.53	243	8,275.53
1969	8,233	64	5.3138	340.08	258	8,831.08
1970	8,834	63	5.8403	367.94	265	9,466.94
1971	9,568	64	6.4774	414.55	279	10,261.55
1972	10,659	63	7.0679	445.28	297	11,401.28
1973	11,615	64	8.7224	558,23	325	12,498.23
1974	12,915	64	9.8450	630.08	348	13,893.08
1975	15,265	63	12.1652	766.24	380	16,411.24
1976	19,300	63	15.0430	947.71	441	20,688.71
1977	22,889	62	16.3413	1013.16	548	24,450.16
1978	26,983	62	19.0360	1180.23	638	28,801.23
1979	29,748	62	23.3829	1449.74	739	31,936.74
1980	33,343	62	27.3798	1697.55	800	35,840.55

Appendix 7.221c

Year Ended March	Total Number of Fatalities	Cost per Fatality (£)	Total Cost of Fatal Accidents (£)
1958	44	5,751.95	253,086
1959	46	5,912.97	271,997
1960	53	6,068.75	321,644
1961	55	6,238.88	343,138
1962	58	6,502.10	377,122
1963	68	6,706.77	456,026
1964	80	6,870.83	549,666
1965	69	7,222.76	498,370
1966	75	7,620.96	571,572
1967	57	7,951.90	453,258
1968	55	8,275.53	455,154
1969	45	8,831.08	387,399
1970	37	9,466.94	350,277
1971	32	10,261.55	328,370
1972	26	11,401.28	296,433
1973	22	12,498.23	274,961
1974	23	13,893.08	319,541
1975	15	16,411.24	246,169
1976	18	20,688.71	372,297
1977	17	24,450.16	415,653
1978	9	28,801.23	259,211
1979	18	31,936.74	574,861
1980	10	35,840.55	358,406

Appendix 7.222a

Year Ended March	Number of Serious Accidents (i) Falls of Ground	Number of Serious Accidents (ii) Transport	Number of Serious Accidents (iii) Machines	Number of Serious Accidents (iv) Misc.	Percentage of Mechanised Longwall Output Per Total Output	Total Number of Serious Accidents on Longwall Mechanised Faces
1958	586	94	54	101	22.8	190
1959	640	99	67	56	27.3	235
1960	631	94	63	46	31.5	263
1961	576	83	50	50	38.5	292
1962	538	83	45	49	48.5	374
1963	553	82	61	54	59.1	443
1964	475	78	62	51	66.3	442
1965	464	68	62	43	72.7	463
1966	375	60	62	45	77.9	422
1967	347	55	51	49	83.0	417
1968	299	56	66	41	87.0	402
1969	200	45	60	40	89.0	307
1970	155	36	52	31	89.7	246
1971	143	33	55	27	90.0	232
1972	112	27	30	44	89.7	191
1973	126	31	31	34	90.5	201
1974	81	31	40	31	91.1	167
1975	81	28	31	30	90.8	154
1976	111	34	31	35	91.4	193
1977	84	35	29	25	91.7	159
1978	101	24	23	37	91.8	170
1979	76	20	37	32	91.6	151
1980	73	16	28	36	91.7	140

Appendix 7.222b

Appendix 7.222c

Year Ended March	Compensation and Common Law Damages Cost per Case (£)	Other Costs per Case (£)	Total Cost per Case of Serious Accidents (£)	Total Number of Serious Accidents	Total Cost of Serious Accidents (£)
1958	680	405.95	1,085.95	190	206,331
1959	705	416.97	1,121.97	235	263,663
1960	720	438.75	1,158.75	263	304,751
1961	755	444.88	1,199.88	292	350,365
1962	785	457.10	1,242.10	374	464,545
1963	820	467.27	1,287.27	443	570,261
1964	870	479.83	1,349.83	442	596,625
1965	905	501.76	1,406.76	463	651,330
1966	930	532.96	1,462.96	422	617,369
1967	990	547.90	1,537.90	417	641,304
1968	1,020	550.53	1,570.53	402	631,353
1969	1,070	598.08	1,668.08	307	512,101
1970	1,160	632.94	1,792.94	246	441,063
1971	1,280	693.55	1,973.55	232	457,864
1972	1,470	742.28	2,212.28	191	422,545
1973	1,650	883.23	2,533.23	201	509,179
1974	2,040	978.08	3,018.08	167	504,019
1975	2,320	1,146.24	3,466.24	154	533,801
1976	2,800	1,388.71	4,188.71	193	808,421
1977	3,200	1,561.16	4,761.16	159	757,024
1978	3,600	1,818.23	5,418.23	170	921,099
1979	4,200	2,188.74	6,388.74	151	964,700
1980	4,900	2,497.55	7,392.55	140	1035,657

Appendix 7.223a

Year Ended March	Face Minor Accidents (i) Falls of Ground	Face Minor Accidents (ii) Haulage & Transport	Face Minor Accidents (iii) Misc.	Percentage of Longwall Mechanised Output per Total Output	Total Number of Minor Accidents on Longwall Mechanised Faces
1958	42,476	5,296	32,332	22.8	18,264
1959	43,447	5,325	34,050	27.3	22,610
1960	42,352	5,013	34,250	31.5	25,709
1961	38,294	4,290	32,485	38.5	28,902
1962	37,100	4,102	32,855	48.5	35,918
1963	37,842	4,124	35,081	59.1	45,535
1964	37,000	3,740	36,229	66.3	51,030
1965	35,751	3,518	36,607	72.7	55,162
1966	34,523	3,365	37,369	77.9	58,625
1967	29,824	2,727	33,968	83.0	55,211
1968	25,663	2,267	30,408	87.0	50,754
1969	20,361	1,774	26,279	89.0	43,088
1970	15,795	1,289	21,695	89.7	34,785
1971	12,241	1,039	17,071	90.0	27,316
1972	9,790	928	14,288	89.7	22,430
1973	7,876	720	12,126	90.5	18,753
1974	7,563	721	12,567	91.1	18,995
1975	5,638	553	10,345	90.8	15,015
1976	6,077	477	11,102	91.4	16,138
1977	5,512	400	10,611	91.7	15,152
1978	5,152	370	10,151	91.8	14,388
1979	4,722	334	9,615	91.6	13,439
1980	3,938	312	8,537	91.7	11,726

Appendix 7.223b

Year Ended March	Total Cost Per Case of Minor Accidents (£)	Total Number of Minor Accidents	Total Cost of Minor Accidents (£)
1958	19.23	18,264	351,217
1959	20.52	22,610	463,957
1960	21.02	25,709	540,403
1961	24.88	28,902	719,082
1962	23.42	35,918	841,200
1963	23.61	45,535	1,075,081
1964	26.06	51,030	1,329,842
1965	29.97	55,162	1,653,205
1966	32.15	58,625	1,884,794
1967	32.48	55,211	1,793,253
1968	33.07	50,754	1,678,435
1969	35.43	43,088	1,526,608
1970	39.94	34,785	1,389,313
1971	45.18	27,316	1,234,137
1972	54.97	22,430	1,232,977
1973	67.84	18,753	1,272,204
1974	76.57	18,995	1,454,447
1975	94.60	15,015	1,420,419
1976	117.00	16,138	1,888,146
1977	127,10	15,152	1,952,819
1978	148.06	14,388	2,130,287
1979	181.87	13,439	2,444,151
1980	212.95	11,726	2,497,052

Appendix 7.224a

Appendix 7224b

Year Ended March	Total No of New Cases of Pneumo-coniosis	Output per Man-shift for all Under-ground (UOMS)	Face Output Per Man-Shift (FOMS)	K	Total No of Cases of Pneumo-coniosis at the Face	Cost per Case of Pneumo-coniosis (£)	Total Cost of Pneumo-coniosis Cases at Face (£)
1958	3,543	1.76	3.64	0.556	1,970	422	831,340
1959	3,057	1.82	3.72	0.563	1,721	425	731,425
1960	3,462	1.80	3.87	0.535	1,852	431	798,212
1961	3,151	1.86	4.09	0.523	1,648	448	738,304
1962	2,619	1.98	4.34	0.525	1,375	462	635,250
1963	2,195	2.11	4.72	0.514	1.128	479	540,312
1964	2,004	2.29	5.03	0.524	1,050	493	517,650
1965	1,162	2.24	5.26	0.490	569	525	298,725
1966	990	2.35	5.57	0.485	480	576	276,480
1967	888	2.42	5.78	0.481	427	602	257,054
1968	752	2.59	6.06	0.492	370	642	237,540
1969	744	2.64	6.71	0.452	336	667	224,112
1970	661	2.78	6.99	0.457	302	684	206,568
1971	736	2.92	7.21	0.466	343	711	243,873
1972	624	2.76	7.05	0.450	281	767	215,527
1973	598	3.00	7.56	0.456	273	805	219,765
1974	521	2.77	7.30	0.436	227	924	209,748
1975	575	2.94	7.89	0.429	247	1,243	307,021
1976	656	2.91	7.89	0.424	278	1,324	368,072
1977	569	2.83	7.75	0.420	239	1,496	357,544
1978	524	2.79	7.91	0.406	213	1,643	349,959
1979	492	2.86	8.53	0.386	190	1,850	351,500
1980	530	2.89	8.88	0.374	198	2,120	419,760

Appendix 7.225

Year Ended March	Total Safety Costs at Current Prices (£)	Price Index	Total Actual Safety Costs At Constant Prices (£)
1958	1,641,974	100.0	1,641,974
1959	1,731,042	102.3	1,692,123
1960	1,965,010	103.1	1,905,926
1961	2,150,889	104.8	2,052,375
1962	2,318,117	108.5	2,136,513
1963	2,641,680	112.5	2,348,160
1964	2,993,783	115.2	2,598,770
1965	3,101,630	119.4	2,597,680
1966	3,350,215	124.8	2,684,467
1967	3,144,869	129.3	2,432,227
1968	3,002,482	133.2	2,254,116
1969	2,660,220	139.7	1,904,238
1970	2,387,221	147.7	1,616,263
1971	2,264,244	158.3	1,430,350
1972	2,167,482	172.2	1,258,700
1973	2,276,109	184.6	1,232,995
1974	2,487,755	203.8	1,220,684
1975	2,507,410	241.0	1,040,419
1976	3,437,036	293.3	1,171,850
1977	3,456,037	339.9	1,016,781
1978	3,660,556	387.5	944,660
1979	4,335,212	426.9	1,015,510
1980	4,310,875	489.7	880,309

Appendix 7.23

Model (4)

Year Ended March	F	T	s	d	p	Predicted Safety Cost from (4) £000	Actual Safety Costs £000	% age Error
1958	774	173	1.41	274	19	1,644	1,642	- 0.12
1959	895	177	1.42	257	30	1,758	1,692	- 3.75
1960	988	181	1.45	251	46	1,902	1,906	0.21
1961	1,090	182	1.51	250	87	2,057	2,052	- 0.24
1962	1,312	187	1.62	241	132	2,461	2,137	-13.17
1963	1,388	199	1.75	242	161	2,879	2,348	-18.44
1964	1,427	205	1.81	244	188	3,089	2,599	-15.86
1965	1,462	207	1.89	246	246	3,197	2,598	-18.74
1966	1.441	208	2.02	243	374	3,000	2,684	-10.53
1967	1,407	210	2.08	239	518	2,639	2,432	- 7.84
1968	1,369	222	2.19	227	699	2,275	2,254	- 0.92
1969	1.025	264	2.17	241	701	1,775	1,904	7.27
1970	898	282	2.16	242	703	1,491	1,616	8.38
1971	849	293	2.08	244	708	1,340	1,430	6,72
1972	840	292	2.09	249	714	1,333	1,259	- 5.55
1973	831	287	2.06	243	718	1,233	1,233	0
1974	778	292	2.03	242	692	1,130	1,221	8.05
1975	745	290	2.04	241	688	1,043	1,040	- 0.29
1976	754	287	2.05	235	687	1,038	1,172	12.91
1977	720	283	2.04	239	686	954	1,017	6.60
1978	709	291	2.04	233	672	945	945	0
1979	673	302	2.08	229	638	936	1,016	8.55
1980	649	314	2.11	230	625	938	880	- 6.18

See Appendix 6.0 for notation.

* Pages 243 - 273 (Appendix 8.0) are inserted in the back cover pocket.

Appendix 8.0

Modelling Process

It is intended here to clarify for the reader exactly how the models introduced earlier, and particularly the indices used, were devised, as well as showing that the models are to a large extent representative of the system, as well as tested by the actual data. Also a simple analysis is carried out to give an indication of the sensitivity of the models to the values of the indices used. All the models are considered here, but to help the reader understand and follow the discussion, the order of appearance will be different from that of sections 3.31 and 3.32 (pp 129-152).

1. Labour Cost Model (page 136)

The first question to be asked is: what factors determine the cost of labour at the coal face? A long list was compiled for these parameters, containing both major and minor ones. From these, those parameters which were either too minor to be considered separately or too difficult to evaluate, such as psychological state of workers, conditions of mines, age of miners and the effect of the state of technology elsewhere underground, were either ignored, assuming them constant over the period under consideration, or included in other variables. For example the effect of technological change elsewhere in the mine can be included in the variable showing the state of technology at the face i.e. tonnage of coal extracted per unit of time, i.e. per shift, T. The pruned list contains these variables:

mean number of faces worked per year (F), mean tonnage of coal extracted per face per shift(T), mean length of face in each year (L) and mean seam thickness of face in each year (B). The equation showing these would be:

$$W = K\,F^{\alpha}\,T^{\beta}\,L^{\gamma}\,B^{\phi}$$

where W is the total face labour cost in each year,

K, α , β , γ and ϕ are constants.

The next stage would be to evaluate the constants. The constant K can be left until the end where it can be evaluated using the actual data.

(a) Evaluation of α

The question asked here is: how does the actual face labour cost vary when the number of faces changes? In other words, for example, if the number of faces increases, what happens to the total cost of labour at the faces? Does it increase of decrease? Taking the number of faces in isolation, i.e. other things being equal, the question becomes an abvious one, for the labour cost of 200 faces, all other things being equal, will be higher than that for 100 faces. Hence α is positive.

$$\alpha > 0$$

The aim is to narrow the scope of the value of α until it is fairly close to its actual value. The pivot now is unity. All other things being equal, then a change in the number of faces is proportional to a change inthe number of men working on the faces. Therefore a positive change in the number of men causes a positive change in the value of W and vice versa. The question now is: if the number of men is doubled, will the total face labour cost double, more than double or less than double? Or, if the number of men is halved, will the total labour cost half, less than half or more than half? Total labour cost is composed of two categories of costs, direct and indirect. When the number of men changes (within a reasonable scope), the direct cost of labour (direct wages) changes by exactly the same proportion. But the indirect or fixed cost of labour does not change proportionately. In other words, if the number of men increases by 10%, the total cost of labour increases by less than 10%. Or, if the number of men decreases by 10%, the total cost of labour decreases by less than 10%, since there are some costs which are constant, and do not depend on the number of men, for example, cost of colliery health centre or the canteen, clerical costs, supervision costs, etc.

Having checked the validity of these statements both through personal interviews with experienced mining engineers and NCB accountants, the conclusion is that α must be less than unity. Therefore:

$$0 < \alpha < 1$$

Now that the above inequalities have been established, let us take the number of faces which is of real interest instead of the number of men, in order to evaluate a more precise value for α. Consulting the NCB accouunts it was deduced that 21 - 30% of the total labour cost, during the period under consideration, has been allocated to the fixed cost of labour. At the same time, as years pass, the mean number of men on each mechanized face tends to decrease, meaning that the total labour cost has been even less responsive to the number of coal faces in operation. This degree of responsiveness can be calculated from figures given in appendices 6.3212 (page 221), 6.321 (page 222) and 6.3243 (page 226) as follows:

$$\text{mean number of men working per shift per coal face in each year} =$$

$$\frac{\text{total number of manshifts worked per year}}{\text{number of days worked per year X number of shifts worked per day X number of faces}}$$

$$= \frac{\text{Total output} \div \text{face OMS}}{d \times s \times F}$$

Table A1 shows the calculation. This table shows the tendency of the number of men employed at the face to have been decreasing. The amount of reduction during the period (excluding years 1972 and 1974) is between (44 - 36) and (45 - 35) i.e. 18-22%. This reduction added to the range already obtained (i.e. 21 - 30%) makes a total of 39 - 52%. Taking the actual values of F, being between 649 and 1462, gives the limits within which the value of α lies.

Year ended March	Mechanised longwall output (m tonnes)	Face O.M.S. (Tonnes)	d	s	F	No. of men per shift per face.
1958	47.6	3.64	274	1.41	774	44
1959	54.7	3.72	257	1.42	895	45
1960	60.8	3.87	251	1.45	988	44
1961	71.4	4.09	250	1.51	1,090	42
1962	89.5	4.34	241	1.62	1,312	40
1963	113.2	4.72	242	1.75	1,388	41
1964	126.1	5.03	244	1.81	1,427	40
1965	135.6	5.26	246	1.89	1,462	38
1966	137.8	5.57	243	2.02	1,441	35
1967	128.2	5.78	239	2.08	1,407	34
1968	144.6	6.06	227	2.19	1,369	35
1969	138.5	6.71	241	2.17	1,025	39
1970	127.4	6.99	242	2.16	898	39
1971	121.8	7.21	244	2.08	849	39
1972	99.6	7.05	249	2.09	840	32
1973	116.7	7.56	243	2.06	831	37
1974	89.9	7.30	242	2.03	778	32
1975	106.0	7.89	241	2.04	745	37
1976	104.5	7.89	235	2.05	754	36
1977	99.4	7.75	239	2.04	720	37
1978	97.5	7.91	233	2.04	709	37
1979	96.6	8.53	229	2.08	673	35
1980	100.3	8.88	230	2.11	649	36

Table A1: Calculation of the number of men per shift per face

$649^{\alpha_1} = 649 \times 0.39$ hence $\alpha_1 = 0.85$

$649^{\alpha_2} = 649 \times 0.52$ hence $\alpha_2 = 0.90$

$1,462^{\alpha_3} = 1,462 \times 0.39$ hence $\alpha_3 = 0.87$

$1,462^{\alpha_4} = 1,462 \times 0.52$ hence $\alpha_4 = 0.91$

The largest space is made by taking the values of α_1 and α_4, therefore:

$$0.85 \leqslant \alpha \leqslant 0.91$$

The gap is now small enough to allow trial and error. The procedure for evaluating α should stop here and the exact value of α which is likely to be 0.85 - 0.91 should be found when similar inequalities are found for other constants.

(b) Evaluation of β

It should be noted here that the parameter T is not taken as representative of the output. It is rather included in the model in order to account for technological change at the coal face and some other minor parameters, i.e. it is in fact, in Abramowitz's[15] term "the residual". It is therefore a parameter representing all other factors but those specifically included in the model. Also, when the modelling process was being carried out, it was noted that a model with only the variables listed earlier would not, in any way, fit the actual data and it was decided that (as will be explained later in sub section (e) of this section) the number of faces equipped with powered supports should also be included in the labour cost model. T is still "the residual", but it now excludes the effects of the introduction and expansion of powered supports.

Evaluation of β is a rather complex procedure. The increase in the value of T over the period has been brought about by both better design and improved equipment, and concentration of workings. The latter would tend to increase labour cost per face while the former is expected to decrease the face labour cost. The situation becomes more complex when it is noticed that better design and improved equipment were brought about not only for productivity improvement, but improved safety was also an aim. A quick look at the statistics of total face labour cost per tonne of coal extracted shows an increase in almost every year leading to the conclusion that β is positive, therefore:

$$\beta > 0$$

If the value of T increased (say) from 200 to 300 in one year and as a result of this change the value of W changed from 100 to 150, the value of β would be unity. If W increased by an amount less than 50 then $0 < \beta < 1$ and if W increased by an amount more than 50 then $\beta > 1$. It was found that the latter is the case, as it is explained here. The mean number of men working on each face is available (see subsection (a)). Wages paid to each man for each shift is also available. From these, the total labour cost for each face is calculated. The aim is to estimate how the price of labour has changed for a tonne of coal to be extracted. The effects of changes in the "machine available time" is therefore necessary to be taken into consideration. For convenience, the variable $\frac{O_m}{MAT}$ from Stanier[140] is used here. It is simply output from longwall mechanised faces in million tonnes per machine available time in minutes. The product of these three values would give an indication of how the real unit price of labour at the coal face has changed. These data are tabulated in Table A2. The mean change of the percentage values is +63%. Now using different values for T during the period the value of β can be calculated. T during the period changes within the limits 173 and 314.

For T = 173: $173^{\beta} = 173 \times 1.63 = 282$ hence $\beta = 1.09$

For T = 314: $314^{\beta} = 314 \times 1.63 = 512$ hence $\beta = 1.09$

Year Ended March	No of men per shift per face	Wages per shift (constant prices) £	Output per machine available time	Real Unit price of labour	% change of unit price of labour
1958	44	3.820	0.608	102	
1959	45	3.880	0.623	109	+ 7
1960	44	3.93	0.617	107	- 2
1961	42	3.95	0.586	97	- 9
1962	40	3.94	0.640	101	+ 4
1963	41	3.81	0.651	102	+ 1
1964	40	3.78	0.635	96	- 6
1965	38	3.90	0.631	94	- 2
1966	35	4.05	0.653	93	- 1
1967	34	3.87	0.628	83	-11
1968	35	3.75	0.723	95	+14
1969	39	3.86	0.794	120	+26
1970	39	3.95	0.867	136	+13
1971	39	3.97	0.900	139	+ 2
1972	32	3.77	0.870	105	-24
1973	37	4.21	0.915	143	+36
1974	32	4.09	0.946	124	-13
1975	37	4.22	0.962	150	+21
1976	36	4.23	0.968	147	- 2
1977	37	4.00	0.977	145	- 1
1978	37	4.18	0.976	151	+ 4
1979	35	4.47	0.988	155	+ 3
1980	36	4.51	0.986	160	+ 3

Table A2 - Changes in the Unit price of labour

For all other values of T during the period the value of β is calculated to be similar. So far the value of β is expected to be around 1.1. But, as indicated above, machines have been designed to result in better conditions of work and higher standards of safety as well as for productivity purposes. This parameter is, however, difficult to be evaluated. The fact that this parameter would tend to increase the value of β was deduced through personal interviews and correspondence with experienced mining engineers and particularly those especialising in the field of safety. It is therefore expected that β will be greater than 1.1, but (remember) by a small amount.

Therefore:

$$\beta > 1.1$$

The exact value of β can now be calculated by trial and error.

(c) Evaluation of γ

This index, being a relatively minor one, was estimated through discussions with mining engineers, with reference to a few articles in the publications of The Institution of Mining Engineers, that tried to find an optimum face length. The first question, again, is: how will total labour cost change with changes of face length? or, all other things being equal, if, for example, a face becomes longer (by a reasonable amount, say 20%), will the number of men working at the face (note that all other things, e.g. tonnage of coal extracted per shift, are being kept equal) tend to increase or decrease? The answer to this being expected to be that of increasing was checked to be true. Therefore:

$$\gamma > 0$$

The question is now: if a face becomes (say) 50% longer, will the number of men working there increase by the same amount i.e. 50% in order to, using the same equipment (but a higher number of powered supports etc. of course), extract the same tonnage of coal per shift? The answer to this was found, through consulting the limited amount of literature available and personal interviews, to be negative. Therefore:

$$0 < \gamma < 1$$

During the whole period 1958-1980, the mean face length has increased by 29% i.e. from 146 to 189. Unfortunately, it was found to be impossible to arrive at an accurate value for γ, using the available statistics. Consultation was therefore once again resorted to. Mining engineers involved in practice, suggest that for 100% (gradual) increase in the length of faces, the total face labour cost is likely to increase by 10-30%. The few available articles, on the other hand, give these limits to be 5-25%. The outer limits are taken here, meaning that when face length increases by 29%, the increase in the total labour cost is likely to be 1.5-8.7%. There is one more fact to be included and that is the tendency to concentrate mining operations on fewer faces which, in turn, may decrease the limits. This is, however, difficult to be estimated. It is, therefore, concluded that the increase in W is between 1.5 and 8.7%, but likely to be in the lower half of the gap.

$$146^{\gamma_1} = 146 \times 0.015 = 2.19 \quad \text{hence} \quad \gamma_1 = 0.16$$

$$146^{\gamma_2} = 146 \times 0.087 = 12.70 \quad \text{hence} \quad \gamma_2 = 0.51$$

It was stated earlier that due to other factors influencing the value of γ, the two limits γ_1 and γ_2 should not be taken to be absolutely accurate, and further, it was indicated that the tendency for γ would be towards the lower side of the limits. To be safe, it is concluded that:

$$\gamma < \tfrac{1}{2}$$

and the exact evaluation of γ is left for the later section where all indices will be found by trial and error.

(d) <u>Evaluation of Φ</u>

This is the index for B, mean seam thickness. For the sa tonnage of coal to be won per shift, assuming all other things b equal, hence the volume of coal per shift won is constant, the thicker the seam the shorter the face need be and therefore the number of men employed would tend to be lower, meaning that the total face labour cost would tend to be lower. That is, if seam thickness increases by (say) 20%, the required face length in order to extract the same volume of coal would be less by approximately 20%. This being an obvious fact, was checked through personal discussions to be true. It is, therefore, established that:

$$\phi \leqslant 0$$

Since the two parameters, namely seam thickness and face length, as described above, can be taken to be inversely proportional, the same argument as given for the evaluation of γ would essentially apply. Due to the inverse proportionality, "other factors" would now tend to increase the change in the value of total labour cost due to a change in the value of seam thickness. The limits obtained in the case of γ would now be, for ϕ, 1-6%, since the value of seam thickness B, has increased by 19% (from 1.25 to 1.49) during the period 1958-1980. Thus:

$$1.25^{\phi} = X$$

when B increases $\quad 1.49^{\phi} = X \times 0.94$

hence: $\quad \phi \log 1.25 = \log X \quad ....(1)$

$$\phi \log 1.49 = \log X + \log 0.94 \quad ....(2)$$

substituting for log X in (2) gives:

$$\phi \log 1.49 = \phi \log 1.25 + \log 0.94$$

hence $\quad \phi = 0.35$

Considering other factors discussed earlier, the value of $\dot{0}$ is most likely to be:

$$\phi \leqslant -0.5$$

(e) The Model

$$W = K\,F^{\alpha}\,T^{\beta}\,L^{\gamma}\,B^{\phi}$$

Actual values of F, T, L and B were substituted in the model. Different values for α, β, γ, and ϕ within the limits obtained above were tried. The values for W calculated in this way were compared with the actual values of W calculated in section 6.3212 pages 136-137. A value of K was adopted so that the two values of W would be equal in 1958. When comparing the two graphs, an insufficiently good fit was observed. After the first few years the graph for the model values of W changed with different rates from that of the actual values graph. Other values for the indices, outside the limits derived, were used which only showed to make the fit worse, implying that the fault had to be in the variables chosen rather than in the values obtained for the indices. Revision of the model was considered to be necessary. The pruned list of parameters must be lacking something. Any such variable would be likely to be related in some way to technology, since this factor was subject to great change during the period. It was then noticed that the effect of introduction and increased use of powered supports was not represented in the original model. However, the number of faces equipped with powered supports grew rapidly in the 1960's after when it slowed down. Different types of functions representing p (number of faces equipped with powered supports) were considered. The rate of increase of p is too sharp for it to be included in the model as it stands and a sort of slower rate of change and hence better behaved would be preferred. Exponential functions are usually well behaved and tend to damp down seasonal and other short term fluctuations. On the other hand and since the values of p are large, it was decided to use the ratio of $\frac{p}{F}$ instead, which is virtually the same but smaller and hence more manageable. The last parameter to be included is therefore $e^{\frac{p}{F}}$. The model would now look like:

$$W = F \; F^{\alpha} \; T^{\beta} \; L^{\gamma} \; B^{\Phi} \; e^{\frac{\theta p}{F}}$$

(f) <u>Evaluation of θ</u>

The first question would again be: when the number of faces equipped with powered supports changes, what happens to the total face labour cost? In other words, when a face changes its support system from props and bars to powered supports, does the number of men needed at the face tend to increase or decrease? Note that all other things are being kept equal. This, being an obvious question itself, was discussed and the answer was verified to be that the more the value of p the less the total face labour cost is expected to be. This means that θ is negative. Therefore:

$$\theta < 0$$

It was further established through articles published by The Institution of Mining Engineers and personal interviews that although faces with powered supports tend to be less labour intensive, in practice, the difference between the two types of faces is small, meaning that the modulus of θ is small. When attempting to estimate a value for θ, the question was: If the ratio $\frac{p}{F}$ doubles, by how much will the mean number of men working at each face decrease?

Widely different estimates were arrived at, ranging from 5% to 20%, implying that the value of θ can be found only approximately. For the reader to follow the argument, the calculation procedure is given here in reverse order. The intention is to find a lower limit for θ.

Let: $\theta = -1$ and $F = 800$ for years t and (t + 1), and

$p = 300$ in year t

$p = 600$ in year (t + 1).

Then $\frac{p}{F} = 3/8 = 0.375$ in year t

$\frac{p}{F} = 3/4 = 0.75$ in year (t + 1) i.e. an increase of 100%

Hence $e^{\frac{\theta p}{F}} = 0.687$ for year t

$e^{\frac{\theta p}{F}} = 0.472$ for year (t + 1)

The value of $e^{\frac{\theta p}{F}}$ shows a reduction of 31.3% which is outside the limits obtained earlier. Therefore

$$-1 < \theta < 0$$

Now let: $\theta = -0.5$, $F = 800$ for years t and (t + 1),

$p = 350$ for year t, and

$p = 700$ for year (t + 1).

Then $\frac{p}{F} = \frac{350}{800} = 0.438$ for year t

$\frac{p}{F} = \frac{700}{800} = 0.875$ for year (t + 1), ie an increase of 100%

Hence $e^{\frac{\theta p}{F}} = 0.804$ for year t

$e^{\frac{\theta p}{F}} = 0.646$ for year (t + 1), ie a reduction of 19.7%.

This reduction is approximately equal to the upper limit mentioned earlier i.e. 20%. It is therefore expected that the value of Θ will be at least 0.5, or:

$$-0.5 \leqslant \Theta < 0$$

The exact evaluation is left for the next section.

(g) The Final Model

The model is now established and approximate values for the indices found. The remaining task is now that of mere calculations to find the best values of these in order that the model values would fit the actual total labour cost values best. Having done this, it was found that the following values for the indices together with the actual values for F, T, L, B and p in each year shows a good fit.

$K = 3.04 \times 10^{-4}$

$\alpha = 0.85$

$\beta = 1.20$

$\gamma = 0.125$

$\phi = -2.0$

$\theta = -0.25$

Using the above gives model values the percentage error between which and the actual labour cost values has a mean of 1.58 and standard deviation of 1.83.

(h) Sensitivity Analysis

A simple exercise will provide the reader with an idea of the accuracy of, and thus add credibility to, the indices used.

The labour cost model obtained in section 6.3211, page 136 was:

$$W = 3.04 \times 10^{-4}\ F^{0.85}\ F^{1.2}\ L^{0.125}\ B^{-2}\ e^{\frac{-p}{4F}}$$

The values of the indices and the constant are changed, one at a time, keeping others constant, to detect the change in the accuracy of the model.

(1) Change K by +10%, i.e. from 3.04×10^{-4} to 3.344×10^{-4}. Values for W, with both values of K together with percentage error in both cases are tabulated in table A3.

The percentage error in the labour cost model values with the old value of K have mean of 1.58 and standard deviation of 1.83, while those with the new value of K (i.e. increased by 10%) have mean of 8.95 and standard deviation of 2.22, which reflects the superiority of the adopted value of K.

Year Ended March	W Model Values with $K = 3.04 \times 10^{-4}$	W Model Values with $K = 3.344 \times 10^{-4}$	Actual Labour Cost	% Error with $K = 3.04 \times 10^{-4}$	%Error with $K = 3.344 \times 10^{-4}$
1958	47.58	52.34	49.98	5.04	- 4.51
1959	54.49	59.94	57.50	5.52	- 4.07
1960	62.81	69.09	61.70	- 1.77	-10.70
1961	68.39	75.23	68.94	0.80	- 8.36
1962	81.13	89.24	81.31	0.22	- 8.89
1963	89.37	98.31	91.29	2.15	- 7.14
1964	94.92	104.41	94.67	- 0.26	- 9.33
1965	101.81	110.37	100.62	0.28	- 8.82
1966	101.81	111.99	100.30	- 1.48	-10.44
1967	90.27	99.30	92.84	2.85	- 6.51
1968	89.60	98.56	89.52	- 0.09	- 9.17
1969	80.13	88.14	79.60	- 0.66	- 9.69
1970	73.55	80.91	72.07	- 2.01	-10.93
1971	71.43	78.57	67.10	- 6.06	-14.60
1972	69.24	76.16	53.26	-23.08	-30.07
1973	66.05	72.66	65.04	- 1.53	-10.49
1974	60.82	66.90	50.34	-17.23	-24.75
1975	56.21	62.61	56.68	- 0.42	- 9.47
1976	56.21	61.83	56.00	- 0.37	- 9.43
1977	51.22	56.34	51.31	0.18	- 8.93
1978	51.66	56.83	51.52	- 0.27	- 9.34
1979	50.42	55.46	50.62	0.40	- 8.73
1980	50.49	55.54	50.89	0.79	- 8.37

Table A3: Effect of 10% increase in K on the labour cost model values

(2) Change α by + 5%, i.e. from 0.85 to 0.89. Values for W with both values for α together with the percentage error in each case are tabulated in table A4.

Year Ended March	W Model Values with $\alpha = 0.85$	W Model Values with $\alpha = 0.89$	Actual Labour Cost	% Error with $\alpha = 0.85$	%Error with $\alpha = 0.89$
1958	47.58	62.08	49.98	5.04	-19.49
1959	54.49	71.51	57.50	5.52	-19.59
1960	62.81	82.76	61.70	- 1.77	-25.45
1961	68.39	90.47	68.94	0.80	-23.80
1962	81.13	108.12	81.31	0.22	-24.80
1963	89.37	119.37	91.29	2.15	-23.52
1964	94.92	126.92	94.67	- 0.26	-25.41
1965	101.81	134.30	100.62	0.28	-25.08
1966	101.81	136.19	100.30	- 1.48	-26.35
1967	90.27	120.64	92.84	2.85	-23.04
1968	89.60	119.61	89.52	- 0.09	-25.16
1969	80.13	105.74	79.60	- 0.66	-24.72
1970	73.55	96.54	72.07	- 2.01	-25.35
1971	71.43	93.55	67.10	- 6.06	-28.27
1972	69.24	90.64	53.26	-23.08	-41.24
1973	66.05	86.43	65.04	- 1.53	-24.75
1974	60.82	79.38	50.34	-17.23	-36.58
1975	56.21	74.16	56.68	- 0.42	-23.57
1976	56.21	73.27	56.00	- 0.37	-23.57
1977	51.22	66.64	51.31	0.18	-23.00
1978	51.66	67.17	51.52	- 0.27	-23.30
1979	50.42	65.42	50.62	0.40	-22.62
1980	50.49	65.42	50.89	0.79	-22.21

Table A4: Effect of 5% increase in α on the labour cost model values.

Labour cost model predicts the labour cost values, the percentage error for which would have mean of 1.58 and standard deviation of 1.83. When α is increased by 5% to 0.89, the mean and standard deviation of the percentage error become 23.95 and 2.02 respectively. It is therefore expected that the accuracy of the model is impaired sharply by any change in the adopted value of $\alpha = 0.85$.

(3) change β by + 5%, i.e. from 1.2 to 1.26. Values of W for both values of β together with the percentage error in each case are tabulated in table A5.

Year Ended March	W Model Values with $\beta = 1.2$	W Model Values with $\beta = 1.26$	Actual Labour Cost	% Error with $\beta = 1.2$	%Error with $\beta = 1.26$
1958	47.58	64.82	49.98	5.04	-22.89
1959	54.49	74.34	57.50	5.52	-22.65
1960	62.81	85.80	61.70	- 1.77	-28.09
1961	68.39	93.45	68.94	0.80	-26.23
1962	81.13	111.04	81.31	0.22	-26.77
1963	89.37	122.78	91.29	2.15	-25.65
1964	94.92	130.64	94.67	- 0.26	-27.53
1965	101.81	138.18	100.62	0.28	-27.18
1966	101.81	140.24	100.30	- 1.48	-28.48
1967	90.27	124.42	92.84	2.85	-25.38
1968	89.60	123.91	89.52	- 0.09	-27.75
1969	80.13	111.97	79.60	- 0.66	-28.91
1970	73.55	103.18	72.07	- 2.01	-30.15
1971	71.43	100.44	67.10	- 6.06	-33.19
1972	69.24	97.34	53.26	-23.08	-45.28
1973	66.05	92.76	65.04	- 1.53	-29.88
1974	60.82	85.50	50.34	-17.23	-41.12
1975	56.21	80.00	56.68	- 0.42	-29.15
1976	56.21	78.94	56.00	- 0.37	-29.06
1977	51.22	71.87	51.31	0.18	-28.61
1978	51.66	72.61	51.52	- 0.27	-29.05
1979	50.42	71.02	50.62	0.40	-28.72
1980	50.49	71.29	50.89	0.79	-28.62

Table A5: Effect of 5% increase in β on the labour cost model values

Again it can be seen that 5% change in the value of β had decreased accuracy of the model sharply, i.e. mean an standard deviation of the percentage error for $\beta = 1.2$ which are 1.58 and 1.83 respectively, have increased to 27.81 and 2.38 respectively.

(4) Change γ by + 10%, i.e. from 0.125 to 0.138. Values for the predicted labour cost using both values of γ, together with the expected percentage error in each case are tabulated in table A6.

Year Ended March	W Model Values with $\gamma = 0.125$	W Model Values with $\gamma = 0.138$	Actual Labour Cost	% Error with $\gamma = 0.125$	%Error with $\gamma = 0.138$
1958	47.58	50.76	49.98	5.04	- 1.54
1959	54.49	58.15	57.50	5.52	- 1.12
1960	62.81	67.05	61.70	- 1.77	- 7.98
1961	68.39	73.04	68.94	0.80	- 5.61
1962	81.13	86.66	81.31	0.22	- 6.17
1963	89.37	95.55	91.29	2.15	- 4.46
1964	94.92	101.53	94.67	- 0.26	- 6.76
1965	101.81	105.14	100.62	0.28	- 4.30
1966	101.81	108.88	100.30	- 1.48	- 7.88
1967	90.27	96.48	92.84	2.85	- 3.77
1968	89.60	95.76	89.52	- 0.09	- 6.52
1969	80.13	85.64	79.60	- 0.66	- 7.05
1970	73.55	78.63	72.07	- 2.01	- 8.34
1971	71.43	76.36	67.10	- 6.06	-12.13
1972	69.24	74.03	53.26	-23.08	-28.06
1973	66.05	70.62	65.04	- 1.53	- 7.90
1974	60.82	65.04	50.34	-17.23	-22.60
1975	56.21	60.88	56.68	- 0.42	- 6.90
1976	56.21	60.13	56.00	- 0.37	- 6.87
1977	51.22	54.80	51.31	0.18	- 6.37
1978	51.66	55.27	51.52	- 0.27	- 6.78
1979	50.42	53.96	50.62	0.40	- 6.19
1980	50.49	54.05	50.89	0.79	- 5.85

Table A6: Effect of 10% change in γ on the labour cost model values

The accuracy of the model has again been impaired by changing γ. The new mean (when $\gamma = 0.138$) is 6.21 and the standard deviation is 2.36, which are considerably higher than those expected when $\gamma = 0.125$ (mean and standard deviation when $\gamma = 0.125$ are 1.58 and 1.83 respectively).

Year Ended March	W Model Values with $\phi = -2$	W Model Values with $\phi = -1.8$	Actual Labour Cost	% Error with $\phi = -2$	%Error with ϕ -1.8
1958	47.58	49.99	49.98	5.04	- 0.02
1959	54.49	56.45	57.50	5.52	- 1.86
1960	62.81	65.89	61.70	- 1.77	- 6.36
1961	68.39	71.74	68.94	0.80	- 3.90
1962	81.13	85.24	81.31	0.22	- 4.61
1963	89.37	94.18	91.29	2.15	- 3.07
1964	94.92	100.03	94.67	- 0.26	- 5.36
1965	101.81	105.42	100.62	0.28	- 4.55
1966	101.81	106.46	100.30	- 1.48	- 5.79
1967	90.27	95.13	92.84	2.85	- 2.41
1968	89.60	94.57	89.52	- 0.09	- 5.34
1969	80.13	84.83	79.60	- 0.66	- 6.17
1970	73.55	78.10	72.07	- 2.01	- 7.72
1971	71.43	75.96	67.10	- 6.06	-11.66
1972	69.24	73.74	53.26	-23.08	-27.77
1973	66.05	70.44	65.04	- 1.53	- 7.67
1974	60.82	65.15	50.34	-17.23	-22.73
1975	56.21	61.06	56.68	- 0.42	- 7.17
1976	56.21	60.38	56.00	- 0.37	- 7.25
1977	51.22	55.17	51.31	0.18	- 7.00
1978	51.66	55.72	51.52	- 0.27	- 7.54
1979	50.42	54.53	50.62	0.40	- 6.17
1980	50.49	54.68	50.89	0.79	- 6.93

Table A7: Effect of 10% increase in ϕ on the labour cost model values

(5) Change Φ by +10%, i.e. from -2 to -1.8. Values for the expected labour cost choosing both -2 and -0.18 for Φ, together with the percentage error in both cases are tabulated in table A7.

The new mean and standard deviation are 5.69 and 2.53 respectively, reflecting the fact that changing the value of Φ by 10% decreases the accuracy of the labour cost model. The mean percentage error increases from 1.58 to 5.69 and the percentage error standard deviation from 1.83 to 2.53.

(6) Change Θ by +10%, i.e. from -0.25 to -0.225. Values for the predicted labour cost choosing both values of Θ, together with percentage error in each case are tabulated in table A8.

It can be seen that a change in the value of Θ has also impaired the accuracy of the model, although by lesser amount than in the case of other indices. In this case, 10% increase in the value of Θ increases the mean percentage error from 1.58 to 2.50 and standard deviation of the percentage error from 1.83 to 1.88.

Year Ended March	W Model Values with $\theta = -0.25$	W Model Values with $\theta = 0.225$	Actual Labour Cost	% Error with $\theta = -.25$	%Error with $\theta = .225$
1958	47.58	47.61	49.98	5.04	- 4.98
1959	54.49	54.54	57.50	5.52	- 5.43
1960	62.81	62.88	61.70	- 1.77	- 1.88
1961	68.39	68.53	68.94	0.80	- 0.60
1962	81.13	81.33	81.31	0.22	- 0.02
1963	89.37	89.63	91.29	2.15	- 1.85
1964	94.92	95.23	94.67	- 0.26	- 0.59
1965	101.81	100.76	100.62	0.28	- 0.14
1966	101.81	102.47	100.30	- 1.48	- 2.12
1967	90.27	91.10	92.84	2.85	- 1.91
1968	89.60	90.75	89.52	- 0.09	- 1.36
1969	80.13	81.51	79.60	- 0.66	- 2.34
1970	73.55	75.00	72.07	- 2.01	- 3.91
1971	71.43	72.92	67.10	- 6.06	- 7.99
1972	69.24	70.73	53.26	-23.08	-24.70
1973	66.05	67.49	65.04	- 1.53	- 3.63
1974	60.82	62.19	50.34	-17.23	-19.05
1975	56.21	58.25	56.68	- 0.42	- 2.70
1976	56.21	57.51	56.00	- 0.37	- 2.63
1977	51.22	52.45	51.31	0.18	- 2.17
1978	51.66	52.90	51.52	- 0.27	- 2.61
1979	50.42	51.63	50.62	0.40	- 1.96
1980	50.49	51.72	50.89	0.79	- 1.60

Table A8: Effect of 10% increase in θ on the labour cost model values

The above results are summarised in table A9.

Change of indices	mean	standard deviation
no change	1.58	1.83
k by +10%	8.95	2.22
α by +5%	23.95	2.02
β by +5%	27.81	2.38
γ by +10%	6.21	2.36
ϕ by +10%	5.69	2.53
θ by +10%	2.50	1.88

Table A9: The effect of change of indices on accuracy of the labour cost model

It is observed from Table A9 that any change in the values of the indices and the constant will impair the accuracy of the labour cost model. In two cases, namely α and β, the model is highly sensitive to any change in the indices.

2. <u>The Output Model</u> (Page 130)

Having gone through the exact procedure by which the labour cost model was devised, and remembering the fact that similar techniques have been used in the case of other models, it is considered that a summary only will suffice in the case of the other five models.

The list of variables in this case consists of the mean number of faces in operation F, the mean tonnage of coal extracted per shift per face T, the mean seam thickness B, the mean number of shifts worked per day s and the mean number of days worked per year d. The model, however, had to be revised, as in the case of the labour cost model, when another variable namely the tonnage of coal lost through stoppages (strikes etc) per year, D, was found necessary to be included.

$$P = (K \; F^{\alpha} \, T^{\beta} \, B^{\gamma} \, d^{\sigma} \, s^{\omega}) - D$$

where P is the total output, and

K, α, β, γ, σ, and ω are constants.

The evaluation of the indices for this model, being a "semi-plausible" one, was simpler than for some of the others. Applying similar techniques, the values of α, β, ω and σ were all found to be around unity. This is explained briefly here. The by now familiar question to be asked is: If the number of faces doubles, all other things being equal, what happens to the total output? In another words, assuming that the coal mining industry is composed of 100 coal faces, all of which are exactly the same in every aspect and they all produce the same tonnage of coal per shift, then if suddenly the number of faces increases to 200, would it not be justifiable to expect the output to double? This assumption is not an impractical one since mean values for all variables are being used. With exactly the same argument the evaluation process of the other indices was initiated. All theoretical work and assumptions made were verified through personal interviews and correspondence. The evaluations of γ was, however, slightly more complicated. Assuming all other things being equal, what happens to the total output when the mean seam thickness increases? Does it increase of decrease? It was established that the former is the case meaning that:

$$\gamma > 0$$

The next step would be to quantify the amount of change in the total output as a result of (say) 100% increase in the value of mean seam thickness. Using the same techniques as in the previous section, a range of 30 - 55% for change of output was obtained. Using the actual change in the period reduces the range to 5 - 9%.

$$1.28^{\gamma_1} = X \qquad \gamma_1 \log 1.28 = \log X \text{ ....(1)}$$

or;

$$1.49^{\gamma_1} = X \times 1.05 \qquad \gamma_1 \log 1.49 = \log X + \log 1.05 \text{ ...(2)}$$

substituting for log X in (2) gives:

$$\gamma_1 \log 1.49 = \gamma_1 \log 1.28 + \log 1.05$$

hence $\gamma_1 = 0.32$

This shows that the lower limit for γ is 0.32. Now to obtain an upper limit, the figure 9% should be used.

$$1.28^{\gamma_2} = Y \qquad \gamma_2 \log 1.28 = \log Y \text{ ....(1)}$$

or:

$$1.49^{\gamma_2} = Y \times 1.09 \qquad \gamma_2 \log 1.49 = \log Y + \log 1.09 \text{ ....(2)}$$

Substituting for log Y in (2) gives:

$$\gamma_2 \log 1.49 = \gamma_2 \log 1.28 + \log 1.09$$

hence $\gamma_2 = 0.57$

Therefore $0.32 \leqslant \gamma \leqslant 0.57$

Having established the above inequalities, the exact value of γ, in order that it would best fit the data, was found by trial and error. The following are the conclusions of these calculations.

$K = 0.84 \times 10^{-6}$

$\alpha = 1$

$\beta = 1$

$\gamma = 0.50$

$\sigma = 1$

$\omega = 1$

Sensitivity analysis of the model gave similar results to those obtained in the case of the labour cost model. That is, the accuracy of the model would be impaired as a result of any change in the value of the indices or the constant K.

(3) Capital Cost Model (page 139)

The procedure by which the variables were adopted is outlined on page 139. In this case it was necessary to break the model into smaller functions. Or, the right way round, it was considered that the combination of five smaller functionswould result in the capital cost model. The cost of capital is dependent upon the number (quantity) of machines purchased, for the cost of (say) 200 shearer loaders should be more than the cost of 100 shearer loaders of the same type and size. Capital cost also depends on the quality of the machinery in use. These are the technological improvements applied to the coal face equipment. Stainer[140] concludes that from 1960 to 1976 the deflated price of mining machinery increased by 6% per year which is in fact "the residual". The cost of machinery also depends on the physical specification of the equipment, e.g. size, for a set of powered supports suitable for a 2 metre thick seam is more expensive than that of the same type but suitable for a 1.5 metre thick seam. Since the actual cost incurred by the NCB for capital equipment is determined by the number and type of machines purchased rather than those actually in use, and since there are always times when machines are temporarily out of use, for example the time elapsed when men of the one shift leave the face and those of the next shift arrive at the face, allowance should also be made for capacity utilization of the machinery available. In addition to this, the NCB always maintain a pool of equipment as stock to cater for the times when machines need to be repaired etc. and hence leave the face. This factor should therefore be considered too. Stainer[140] found that approximately half of the face machines purchased by the NCB are actually installed at the faces. Each of these factors depends upon a number of variables. The exact variables used (or the pruned list) are outlined on pages 139 and 140. The indices were calculated in much the same way asthose in the case of the labour cost model, although in this case considerably more calculations were required. For example the model was subject to major revision four times in this case. Sensitivity analysis of the model confirmed its accuracy, for as a result of changing any of the indices or the constant, the accuracy of the model was impaired.

(4) Safety Cost Model (pages 148 and 183)

The argument for choosing the variables is as follows. Basically, the more the number of men working at a face, the higher the probability that one of them would have an accident. For example, it is axiomatic that, all other things being equal, the probability of an accident occurring during any shift at a face with 40 people working is higher than that where 10 people work. Therefore the number of faces needs to be considered, together with a variable representing concentration of workings, here T. Further, if a man works two shifts per day, he is more succeptible to having an accident in any day than if he works one shift per day. Therefore the mean number of shifts worked per day s, is taken into account. Also, the probability of having an accident in any year is higher for the man who works 300 day per year (note that all other things are being kept equal and the man is the average man) than for the one who works 100 days per year, therefore the mean number of days worked per year foreach worker d, needs to be included. The only factor remaining is a variable representing the fact that faces equipped with powered supports are much safer than those without, due to the reduced area of exposed roof at faces using powered supports. For the same reason as before (see Section 1) an exponential function incorporating p, the number of faces equipped with powered supports, is used. Apart from all these, as was mentioned several times before, there is a strong psychological element attached to the occurrence of accidents. This is assumed constant, mainly because it is difficult, if not impossible, to be evaluated. For this reason a lower degree of accuracy from this model will be accepted. The indices have been calculated in the same way as described for previous models and those best fitting the model have been adopted, but the mean and standard deviation of the errors are, expectedly, higher for this model than for most of the others. Sensitivity analysis confirms the superiority of the indices used.

5. <u>Materials and Supplies Cost Model</u> (page 149)

$$M = \frac{4.495 \times 10^{-5} \quad F^{1.3} \qquad d \quad s}{T}$$

A brief argument is given here for the way in which this model was devised. The first step would be to compile a list of variables. The three main variables affecting materials and supplies cost are: quantity of machines, rate of use and the state of technology. The number of machines used is represented by F, the mean number of coal faces in operation. This variable also includes the fact that faces have become longer and thicker over the period under consideration. For the higher the number of faces in operation the higher the number of machines in use and hence the higher the cost of repair, maintenance etc should be, the index of F must be positive. This combined with other parameters such as seam thickness and face length established the value of this index to be 1.05 - 1.35, which was the basis for trial and error procedure in order to find the exact value of the index of F. The rate of use, the argument for which is similar to that for the safety cost model, is represented in the model by the inclusion of two variables d, the mean number of days worked per year, and s, the mean number of shifts worked per day. Technology, together with some other minor parameters, is again represented by T, the mean tonnage of coal extracted per shift. For, the higher the level of technology, the higher the value of T (note that all other things are being kept equal) and the lower the materials and supplies cost would be, the index for T would be negative. All these and other assumptions and estimates have been discussed and verified through personal interviews and correspondence with mining engineers. Trial and error, as before, gives the precise value of the indices and the sensitivity analysis applied to the model confirms their superiority.

6. <u>Power Cost Model</u> (page 151)

It was mentioned on page 149 that power cost is in fact a part of the materials and supplies cost and it is dealt with separately because of possible interesting and useful conclusions that it may provide. Forthis reason, the argument for the choice of varia.bles is similar to that in the case of the materials and supplies cost model. The variable T here is to represent the rate of use of electrically powered machines within any shift, concentration of workings and the level of technology i.e. more sophisticated machinery and the use of more ancillary equipment, e.g. methane drainage equipment. F, on the other hand is to represent the number of electrical machines used, which varies with the number of faces in operation. The fact that the index for F is less than unity indicates the fixed power consumption which is independent of the rate of coal production. Having obtained limits for the indices, the trial and error procedure gave the precise values of these and the sensitivity analysis, which was applied to this model in the same way as in the case of the labour cost model, confirmed the superiority of the indices used.

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